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The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 850 copies. A small supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society. A discount of ten (10) per cent is allowed to persons residing elsewhere than in North America and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

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Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 40 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

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Proceedings of the Paleontological Society.

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CORRECTIONS AND INSERTIONS

Contributors to volume 35 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 49, line 16 from top, *for* "Northern Pacific" *read* Great Northern
" 51, line 15 from top, *for* "following" *read* and was followed by
" 142, line 8 from bottom, *insert* John L. Tilton
" 310, bottom line, *for* "H_2O" *read* H_2O+
Pages 387, 409, 419, 420, 421 and 422 *for* "Couteau" *read* Coteau
Page 419, line 5 from bottom, *for* "Bevans" *read* Bevan
" 426, line 24 from top, *for* "the same" *read* same
" 430, line 24 from top, *for* "page —" *read* pages 428-429
" 434, footnote 17, *for* "p. —" *read* p. 431
" 467, page heading, *for* "illustration" *read* description
" 467, under figure title, for "Drawn on the assumption" *read* Drawn on the incorrect assumption [The author's interpretation is given in section L-L′ on page 477]
" 468, line 8 from bottom, table should read as follows:

Ordovician	Cocalico shale (1,000′±)	Conestoga limestone (500′±) 500′±–1,000′±
	Unconformity	
	Beekmantown limestone	2,000′±

Page 474, line 6 from top, *for* "being" *read* there being
" 485, plate 23, *insert plate title* Lance Formation, Montana
" 493, plate 24, *insert plate title* Fort Union and Lance Formations, Montana
" 495, plate 25, *insert plate title* Fort Union and Lance Formations, Montana
" 540, line 2 from bottom, *for* "538" *read* 539
" 552, line 11 from top, *for* "Canalieuli" *read* Canaliculi
" 575, line 3 from bottom, *for* "operations" *read* operation
" 587, line 8 from top, *for* "afficacy" *read* efficacy
" 587, last line, *for* "colloidal" *read* amorphous

‡ Bearing imprint [From BULL. GEOL. SOC. AM., VOL. 34, 1922.]

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 1-160, PLS. 1-5 MARCH 30, 1924

PROCEEDINGS OF THE THIRTY-SIXTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT WASHINGTON, D. C., THURSDAY-SATURDAY, DECEMBER 27-29, 1923.

CHARLES P. BERKEY, *Secretary*

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Session of Thursday Morning, December 27, 1923

The Thirty-sixth Annual Meeting of the Geological Society of America was called to order in the Auditorium of the Department of the Interior Building, Washington, D. C., at 9.10 a. m., by President David White. Brief introductory remarks were made by the presiding officer, who called attention to the advantages of meeting in this scientific center and in the midst of so large a community of active geological investigators.

Report of the Council

The report of the Council was presented by Secretary Berkey, as follows:

To the Geological Society of America, in thirty-sixth annual meeting assembled:

The regular annual meeting of the Council was held at Ann Arbor, Michigan, in connection with the meeting of the Society, December 27-29, 1922. Special meetings were held, one in Washington, D. C., on April 19, 1923, and the other in New York City on October 7, 1923.

The details of administration for the thirty-fifth year of the existence of the Society are given in the following reports of the officers.

President's Report

To the Council of the Geological Society of America:

The President's report for the year ending November 30, 1923, is as follows:

Several important matters of policy have been considered by the Council at the April and October meetings, some of which are still pending. Chief among these are the questions of preparation of a suitable abstract for each title offered, the organization of a program plan, the enlargement of the list of foreign correspondents, the distribution of the Bulletin, and questions connected with the establishment in America of a geological abstract journal.

The principal activities of the Council outside of the regular administrative work of the different responsible officers have been carried on through the following committees:

Membership Committee: T. Wayland Vaughan, L. C. Graton, L. G. Westgate.

Program Committee—Subcommittee on Program: Fred. E. Wright, L. C. Graton, E. T. Wherry, C. P. Berkey.

Subcommittee on Abstracts and Presentation of Papers: James F. Kemp, W. M. Davis, Frank D. Adams.

Committee on Teaching Geology: W. J. Mead, C. P. Berkey, George F. Kay, Eliot Blackwelder, H. L. Fairchild, F. L. Ransome.

Committee on Foreign Correspondents: James F. Kemp.

Committee on Exchanges: Charles Schuchert.

Committee on Investment: I. C. White, Whitman Cross, J. Stanley-Brown.

Committee on Publication: James F. Kemp, E. O. Hovey, J. Stanley-Brown.

Local Committee for the Washington Meeting: Gerald F. Loughlin, J. F. Katz, P. V. Roundy, F. E. Matthes, A. C. Spencer, D. F. Hewett, Edward Sampson.

During the year a number of important appointments have been made of representatives and delegates to scientific meetings and to represent the Society at public functions and celebrations, as follows:

The Joseph A. Holmes Safety Association: Delegate, John J. Rutledge.

The Society of Economic Geologists: Council Representative, James F. Kemp.

The Pan-Pacific Scientific Conference: Delegates, E. O. Hovey, T. Wayland Vaughan, William H. Hobbs, Alfred H. Brooks, N. M. Fenneman, Herbert E. Gregory, Henry S. Washington.

The British Association for the Advancement of Science: Delegate, John M. Clarke.

The Joseph Leidy Commemorative Meeting: Delegates, Henry Fairfield Osborn, William B. Scott, Charles D. Walcott, R. A. F. Penrose, Jr., David White.

Inauguration of Cloyd Heck Marvin, President of the University of Arizona, April 23, 1923: Delegate, G. Montague Butler.

Dedication of the Steward Observatory at Tucson, Arizona, April 23, 1923: Delegate, G. Montague Butler.

Inauguration of Samuel Wesley Stratton, President of Massachusetts Institute of Technology, June 11, 1923: Delegates, Waldemar Lindgren, Hervey W. Shimer, W. O. Crosby.

Inauguration of Harlan Updegraff, President of Cornell College, Mount Vernon, Iowa, October 19, 1923: Delegate, William H. Norton.

Inauguration of Herbert Spencer Hadley, Chancellor of Washington University, November 10, 1923: Delegate, Henry Andrew Buehler.

Respectfully submitted, DAVID WHITE,
President.

SECRETARY'S REPORT

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30, 1923, is as follows:

Meetings.—The proceedings of the annual general meeting of the Society, held at Ann Arbor, Michigan, December 27-29, 1922, have been recorded in volume 34, pages 1-116 of the Bulletin. Those of the Cordilleran Section, pages 117-120; of the Paleontological Society, pages 121-142; of the Society of Economic Geologists, pages 143-146; of the Mineralogical Society of America, pages 147-150, of the same volume.

Membership.—During the last year the Society has lost four Fellows by death—Anthony Wayne Vogdes, Horace V. Winchell, Raphael Pumpelly, and Richard C. Hills. The names of the seventeen Fellows elected at the Ann Arbor meeting have been added to the printed list. Five Fellows have been dropped from the rolls for non-payment of dues. The present enrollment of the Society is 483. Twenty candidates for Fellowship are before the Society for election and six for correspondentship, and several applications are under consideration by the Council.

Distribution of the Bulletin.—During the past year there have been sent out to subscribers 173 copies of volume 34 of the Bulletin, 20 going to new subscribers. Five volumes have been distributed gratis, as follows: Library of Congress, American Museum of Natural History, the Government Geological Surveys of the United States, Canada, and Mexico. Fifty-nine copies have been sent to our foreign exchange list. The receipts from subscriptions to and sales of the Bulletin and separate

brochures therefrom, amounting to $3,110.11, appear in the Treasurer's report.

Detailed Financial Statement of the Secretary's Office

ON ACCOUNT OF ADMINISTRATION

Expenses, Ann Arbor meeting:		
Printing	$207.75	
Badges	20.00	
Suitcase, etcetera	11.60	
		$239.35
Printing for 1923		250.75
Equipment for new Secretary's office:		
File cabinet	$26.20	
Addressograph machine	83.00	
Shelving	137.81	
		247.01
Moving expenses of Secretary's office		60.50
Cordilleran Section:		
Secretarial expenses	$14.61	
Printing	43.40	
		58.01
Framing group portrait for office of Secretary		4.75
Postage		141.51
Telegrams and telephone calls		25.32
Clerical help		220.00
Carfare		.75
Notary fees		.75
Addressograph plates		5.34
Exchange on checks		2.89
Repairing typewriter		1.00
Cost of shipping set of Bulletins to Czechoslovakia		26.75
Miscellaneous supplies		27.50
Total		$1,312.18

ON ACCOUNT OF BULLETIN

200 separates, Kemp Presidential address		$22.35
9,000 envelopes for mailing Bulletin		156.00
Office expenses:		
Express and postage	$95.98	
Telegrams and telephone	3.79	
Drafting work on manuscripts (refunded)	4.25	
Carfare	1.30	
Addressograph plates and ribbon	3.59	
Exchange on checks	1.60	
		110.51
Total		$288.86

Respectfully submitted, CHARLES P. BERKEY,
Secretary.

TREASURER'S REPORT

To the Council of the Geological Society of America:

The Treasurer herewith submits his report for the year ending November 30, 1923.

The membership of the Society on December 1, 1922, consisted of 372 paying annual dues, 91 Life Members, and 11 Correspondents. Eighteen new members qualified during the year, 3 as Life Members; the remainder, 15, paying annual dues. One Life Member and 3 Annual Members have died during the fiscal year and 5 have been dropped for the non-payment of dues. As the books close, the membership consists of 93 Life Members, 379 Annual Members, and 11 Correspondents, making a total of 483.

The fees receivable at the beginning and close of the year are as follows:

	Receivable December 1, 1922	Collected November 30, 1923	Due November 30, 1923
Fees of delinquents (1919-1922)	$420.00*	$250.00	$40.00
Annual fees (1923) at $10	3,870.00†	3,640.00	170.00
Advanced payments (1924)	20.00	20.00	.....
		3,910.00	
Initiation fees (18) at $10	180.00	180.00	.....
Life Commutations (3) at $150	450.00	450.00	.....
	$4,940.00	$4,540.00	$210.00

RECEIPTS

Cash in bank December 1, 1922		$3,886.30
Annual dues:		
From delinquents	$250.00	
For 1923	3,640.00	
For 1924	20.00	
		3,910.00
Initiation fees (18) at $10		180.00
Life Commutations (3) at $150		450.00
Interest:		
On investments	$1,485.00	
On deposits	145.10	
Foreign exchange added to checks	.49	
		1,630.59

* Includes $130 due from delinquent members dropped during the year.

† Includes $50 due from delinquent members dropped during the year and $10 paid in advance in 1922.

Redemption of bonds:			
Bell Telephone	$1,075.00		
Florida Central and Peninsular	1,000.00		
		2,075.00	
Received from Secretary:			
Sales of publications	$3,110.11		
Authors' separates	441.13		
Authors' corrections	38.70		
Drafting work on manuscripts (refund)	4.25		
Postage and express refund	23.47		
Exchange on checks refund	1.52		
Group portrait	6.00		
Geological Magazine	170.00		
Programs	15.25		
		3,810.43	
			$15,942.32

DISBURSEMENTS

Secretary's office:			
Administration	$1,312.18		
Bulletin	288.86		
Portrait	5.00		
Geological Magazine	205.99		
Allowance	1,000.00		
		$2,812.03	
Treasurer's office:			
Expenses	$151.00		
Clerk	150.00		
		301.00	
Publication of Bulletin:			
Printing	$3,577.44		
Engraving	605.16		
Paper	1,050.92		
Editor's salary	250.00		
		5,483.52	
Mineralogical Society of America		102.00	
Investments:			
2 Anaconda Copper Company bonds	$1,938.00		
2 American Telegraph and Telephone Company bonds	1,970.00		
		3,908.00	
Accrued interest in coupons		28.12	
Purchase of Bulletins		22.00	
			$12,656.67
Balance in Baltimore Trust Company			3,285.65
			$15,942.32

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The following tables cover statistical data for the thirty-four volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost.	Average—Vols. 1-30.	Vol. 31.	Vol. 32.	Vol. 33.	Vol. 34.
	pp. 737. pls. 31.	pp. 468. pls. 14.	pp. 506. pls. 12	pp. 862. pls. 5.	pp. 778. pls. 20.
Letter press	$1,776.16	$1,541.45	$1,883.18	$3,006.32	$2,572.34
Illustrations	433.34	131.94	272.44	616.01	499.36
Paper	428.12	266.64	792.00	686.81	424.87
Total	$2,566.03	$1,940.03	$2,947.62	$4,309.14	$3,496.57
Average per page	$3.51	$4.15	$5.83	$5.00	$4.62

CLASSIFICATION OF SUBJECT-MATTER

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of Pages.											
1....	116	137	92	18	83	44	47	...	60	4	4	593+xii
2....	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3....	56	41	44	41	32	158	104	...	61	15	1	541+xii
4....	25	134	38	74	52	52	14	...	47	32	2	458+xii
5....	138	135	70	54	28	51	107	...	71	14	9	665+xii
6....	50	111	75	39	71	99	1	...	63	25	4	538+x
7....	38	77	105	53	40	21	123	4	66	28	13	558+x
8....	34	50	98	5	43	67	58	14	79	8	...	446+x
9....	2	102	138	...	44	28	64	16	64	12	...	460+x
10....	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11....	65	110	21	10	54	31	188	7	71	60	46	651+xii
12....	199	39	55	53	24	98	5	5	70	2	...	538+xi
13....	125	17	13	24	28	116	42	4	165	32	29	583+xii
14....	48	47	48	59	183	118	22	1	80	14	1	609+xi
15....	26	124	3	94	36	267	...	...	77	17	3	636+x
16....	64	111	78	30	102	141	19	...	67	22	15	636+xiii
17....	49	161	41	84	47	294	27	...	71	9	2	785+xiv
18....	16	164	141	5	29	246	5	...	68	40	3	717+xii
19....	106	108	29	66	30	155	32	...	56	15	20	617+x
20....	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21....	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22....	23	54	28	28	23	403	74	...	63	49	1	747+xii
23....	75	52	126	108	19	145	134	...	66	32	1	758+xvi
24....	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25....	34	211	54	32	156	9	175	...	108	9	22	802+xviii
26....	...	72	23	11	56	90	148	...	54	44	6	504+xxi
27....	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28....	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29....	3	107	62	15	127	169	64	...	73	57	21	679+xix
30....	160	3	41	9	5	36	205	16	73	59	50	644+xiii
31....	1	80	19	4	13	45	22	21	69	97	79	450+xviii
32....	73	47	7	27	63	51	77	17	105	2	37	488+xviii
33....	39	166	160	47	97	107	101	3	91	41	31	862+xxi
34....	20	256	73	2	39	149	48	...	89	38	64	778+xx

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL.

December 27, 1923.

ELECTION OF AUDITING COMMITTEE

The printed report of the Council was distributed to all members in attendance. Since the report of the Council contained the Treasurer's report, it was laid on the table pending examination of the Treasurer's accounts and report of an auditing committee named from the floor, consisting of Sidney Paige, chairman, E. H. Kraus, and Adolph Knopf.

ELECTION OF OFFICERS, MEMBERS OF STANDING COMMITTEES, CORRESPONDENTS, AND FELLOWS

The Secretary then read the result of the counting of the ballots for officers and members of standing committees for 1924, and of the ballot for Correspondents and Fellows, resulting from the canvas made by mail. On the basis of these returns the following were declared elected:

President:

WALDEMAR LINDGREN, Cambridge, Massachusetts

First Vice-President:

WILLIAM A. PARKS, Toronto, Canada

Second Vice-President:

JOHAN A. UDDEN, Austin, Texas

Vice-President to represent the Paleontological Society:

EDWARD W. BERRY, Baltimore, Maryland

Vice-President to represent the Mineralogical Society:

HENRY S. WASHINGTON, Washington, D. C.

Secretary:

CHARLES P. BERKEY, New York City

Treasurer:

EDWARD B. MATHEWS, Baltimore, Maryland

Editor:

JOSEPH STANLEY-BROWN, New York City

Councilors (1924-1926):

FRED. E. WRIGHT, Washington, D. C.
WILLIAM H. TWENHOFEL, Madison, Wisconsin

Representatives on the National Research Council (July 1, 1924, to June 30, 1926):

HEINRICH RIES, Ithaca, New York
GEORGE R. MANSFIELD, Washington, D. C.

CORRESPONDENTS

SIR THOMAS W. EDGEWORTH DAVID, Sydney, New South Wales, Professor of Geology, University of Sydney.

JAKOB JOHANNES SEDERHOLM, Helsingfors, Finland, Director, Geological Survey of Finland.

FRANCOIS ANTOINE ALFRED LACROIX, Paris, France, Director, Mineralogical Laboratory, Natural History Museum.

ARTHUR SMITH WOODWARD, London, W., England, Keeper, Geological Department, British Natural History Museum.

GUSTAAF ADOLF FREDERIK MOLENGRAAFF, Delft, Holland, Professor of Geology, Technische Hoogeschool.

BUNJIRO KOTO, Tokyo, Japan, Professor of Geology and Paleontology, Tokyo Imperial University.

FELLOWS

LESLIE PARK BARRETT, B. S., Assistant State Geologist and State Mine Appraiser, Geological Survey of Michigan, Lansing, Michigan.

CLYDE MAX BAUER, Sc. B., Chief Geologist, Mid-Northern Oil Company, Billings, Montana.

WALTER ANDREW BELL, B. Sc., Ph. D., Associate Paleobotanist, Victoria Memorial Museum, Ottawa, Canada.

FERDINAND JULIUS FOHS, Consulting Geologist, New York City.

JOHN W. GRUNER, B. A., M. S., Ph. D., Assistant Professor of Geology, University of Minnesota, Minneapolis, Minnesota.

GEORGE SHERWOOD HUME, B. A., Ph. D., Associate Geologist, Geological Survey of Canada, Ottawa, Canada.

WILLIAM KENNEDY, Chief Geologist, Lone Star Gas Company, Dallas, Texas.

CHESTER RAY LONGWELL, A. B., M. A., Ph. D., Assistant Professor of Geology, Yale University, New Haven, Connecticut.

FRANK HARRIS MCLEARN, B. E., Ph. D., Associate Invertebrate Paleontologist, Geological Survey of Canada, Ottawa, Canada.

JOHN BEAVER MERTIE, JR., A. B., Ph. D., Geologist, U. S. Geological Survey, Washington, D. C.

LOUIS E. REBER, JR., B. S., Ph. D., Chief Geologist, United Verde Copper Company, Jerome, Arizona.

GEORGE MELVIN SCHWARTZ, B. A., M. A., Ph. D., Assistant Professor of Geology, University of Minnesota, Minneapolis, Minnesota.

IRVING DAY SCOTT, A. B., A. M., Ph. D., Associate Professor of Physiographical Geography, University of Michigan, Ann Arbor, Michigan.

HOWARD EDWIN SIMPSON, Ph. B., A. M., Professor of Geographic Geology, University of North Dakota, and Geologist, North Dakota Geological Survey, Grand Forks, North Dakota.

MALCOLM RUTHERFORD THORPE, B. A., Ph. D., Assistant Curator and Research Associate in Vertebrate Paleontology, Yale University, New Haven, Connecticut.

EDWARD LEFFINGWELL TROXELL, A. B., A. M., Ph. D., Assistant Professor of Geology, Trinity College, Hartford, Connecticut, Research Associate in Vertebrate Paleontology, Yale University, New Haven, Connecticut.

STEPHEN SARGENT VISHER, B. S., M. S., Ph. D., Associate Professor of Geology, Indiana University, Bloomington, Indiana.

CHESTER KEELER WENTWORTH, B. S., Ph. D., Instructor in Geology, State University of Iowa; Associate Geologist, U. S. Geological Survey, Iowa City, Iowa.

FRANCIS LUTHER WHITNEY, A. B., A. M., Associate Professor of Geology and Paleontology, University of Texas, Austin, Texas.

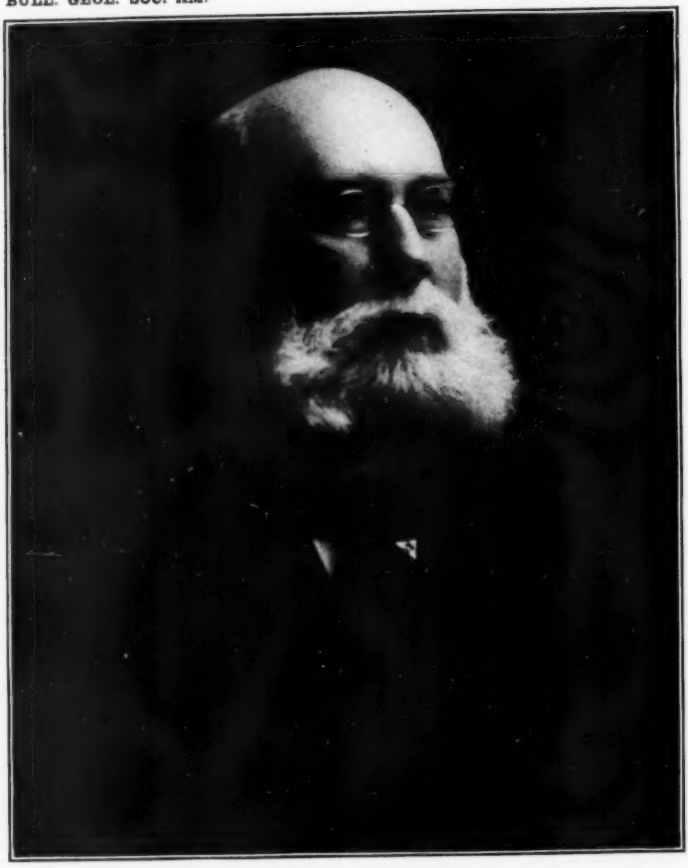
WILLIAM EMBRY WRATHER, Ph. B., Consulting Gologist, Dallas, Texas.

NECROLOGY

The Secretary announced the deaths during the year of four Fellows of the Society, all but one of whom were original Fellows. Brief oral tributes were then called for as follows: Richard C. Hills, by R. D. George; Raphael Pumpelly, by Bailey Willis; Anthony Wayne Vogdes, by E. T. Dumble; Horace Vaughn Winchell, by James F. Kemp.

In the absence of Bailey Willis, the tribute prepared by him was read by the Secretary. R. D. George, who has undertaken the preparation of a memorial for Richard C. Hills, was unable to be present; and E. T. Dumble, who had already prepared the memorial for Anthony Wayne Vogdes, was not present to give the oral tribute.

The written memorials are printed in the Proceedings. In addition to these already listed, the memorial of M. E. Wadsworth, by A. C. Lane, held over from last year, and the memorial of J. W. W. Spencer, by E. W. Shaw, are also included.



M. E. Wadsworth.

MEMORIAL OF MARSHMAN E. WADSWORTH[1]

BY ALFRED C. LANE

The life of a man of science is often divided into three parts: Education and early training in preparation for his work; investigation, in which he is actively pushing forward the frontiers of organized knowledge; and administration, in which he supervises the work of others. This makes a convenient framework for this memorial, although since the second part is of especial interest to members of this Society the other parts can be curtailed. Outside of personal letter files and acquaintance, my authorities are mainly those stated below.[2]

The education of a man begins before he is born, and it is worth noting that Wadsworth wrote upon family genealogy and belonged to that New England family of President Wadsworth, of Harvard, after whom Wadsworth House was named. Born on a farm in Livermore Falls, Maine, May 6, 1847, when sixteen he entered the preparatory course for Bates College, studied at Lewiston Falls Seminary, matriculated at Bowdoin in 1865 and graduated in 1869, when twenty-two years old, having taught one to three terms a year, from the time he was sixteen, in order to work his way through. He was thus in actual residence but forty-two weeks and three days. Thus early a teacher—we might say a born teacher—he got a strong flavor of the pedagogue that lasted through life. He was helpful to his students and popular with them (all the more, perhaps, because he showed their errors plainly), for he showed a real interest in them. His rather blunt manner of correcting errors was not so gratefully received by his colleagues in research.

After taking his A. M. in 1872 at Bowdoin, having taught in Minnesota and Wisconsin, he went to Harvard, studied with Agassiz, was professor of chemistry at Boston Dental College in 1873, instructor in mathematics and mineralogy, 1874-77, and assistant to J. P. Cooke and C. E. Monroe in 1876; in 1877 became assistant in the Museum of Comparative Zoology to N. S. Shaler, and thereafter to 1887 was closely associated with J. D. Whitney, in connection with whom much of his important research was done. His varied career at Harvard University showed both a range of training and a zeal as assistant that was not too deferential to the heads of the department, and of this there are still traditions. He took his doctor's degree in 1879.

[1] Manuscript received by the Secretary of the Society August 14, 1923.

[2] Who's Who for 1920, and Who's Who in the Pitt Weekly, May, 1915 (a copy sent me by M. E. W., with corrections); also "Poppy Wadsworth," by K. E. Davis, April 27, 1921, and Daily Mining Gazette of Houghton, August 11, 1916. See also Engineering and Mining Journal, vol. 52, 1891.

His thesis, "Classification of rocks," was never published as such. It was one of the early papers to repudiate age as a basis for names, was deemed by Wolff valuable indeed, and much of it was incorporated in Wadsworth's report as State Geologist and in catalogues of the College of Mines.

Having taught mathematics, mineralogy, and chemistry, he was well prepared to enter the new field of microscopic petrography, in which he was one of the pioneer instructors in America. His first publication was before the Boston Society of Natural History in 1887, and he was a very active member of this Society for the next seven years, the most scientifically fruitful period of his life. There still comes to the few survivors a delightful thrill, that of watching a fight, when they recall the meeting when T. Sterry Hunt came in, having come down from Montreal, just in time to hear Wadsworth's review of his work in his most caustic style.[3]

His scientific work was of a twofold character—positive and negative. He recognized and described many igneous rocks, both around and in New Hampshire and Michigan. He identified many as such that Hunt and others had taken as altered sediments, and did a good deal to overthrow the elaborate and fanciful system of subdivisions of the pre-Cambrian which had been built up by Hunt. He did particularly extensive work on the less silicious rocks, the serpentines and meteorites, but was one of the first also to recognize the felsites around Boston, which had been taken for sediments, as igneous rocks. Although he went too far in classing the jaspilites as igneous, those who sneer at his error should think of the Lapland and Iron Mountain ores before too hasty condemnation. He recognized the character of hornblende as uralitic after pyroxene in many cases, and, having been associated with Pumpelly, it was not surprising that he was early among those who recognized the extensive change of rocks while in their solid condition. He thus recognized the essential identity of the Tertiary or later, and pre-Tertiary rocks, and in his doctor's thesis classified the igneous rocks with no regard to age. Through his association with Whitney he was led to study the Michigan rocks, and then called upon by Prof. N. H. Winchell to study petrographically some of the Minnesota rocks. In 1874 he was with the New Hampshire Survey, and was Geologist of the Pennsylvania State Board of Agriculture from 1902 to 1905. He reviewed the fortieth parallel work of Zirkel and pointed out some errors which made him enemies in important places. His work with Whitney, while aimed to establish the Azoic period, caustically showed up much of the unsatis-

[3] See Bibliography No. 19, and 48, the Azoic System. Hunt is said to have been almost incoherent with rage.

factory work of Hunt and others. In his Michigan work he made some errors. The Keweenaw Series which, as he noticed, is thrust in some places over, he took to be later than the Eastern Sandstone. As he had so severely criticised others, so it pleased others the more to criticise him. But though blunt in his expression of opinion, he did not cherish malice. As he wrote me January 8, 1899:

"Your kind favor of the 2nd instant received, and I thank you very much for the kind words you have written me and wish you the best of success yourself. Please do not trouble yourself over the difference of opinion that you and I have had on any matter, for, however much I may have discussed matters with you, I never retained any personal ill-feeling or ill-will toward you for a minute."

He was associate editor of the American Geologist 1894 to 1899.

In educational matters Doctor Wadsworth was progressive to a degree. Called to Colby University in 1885, where he was succeeded by W. S. Bayley, he organized the department there. When, in 1887, he was called to the Michigan College of Mines it was occupying quarters in an abandoned skating rink. When he left it, in 1899, it was, in quarters and equipment, below none in the country, and had become the largest mining school in America, and had had well known men associated with it. General R. I. Rees was secretary; well known in mining are Denton, of the Copper Range; R. M. Edwards, Moldenke Hood, Sharpless, now secretary of the American Institute of Mining Engineers; in geology, L. L. Hubbard, afterward State Geologist; H. B. Patton; F. E. Wright; and Seaman, McNair, and Spurr, still connected with the institution. He seemed to have a good eye for men (even the janitor, Harry Gibbs, has risen); his judgment of women was more questionable.

He left apparently not because of any academic trouble (except, as has been hinted to me, a case of enforced discipline may have alienated an influential man), but rather because of domestic difficulties. He married three times. His second wife he divorced while in Houghton, and the charges and countercharges were not edifying. The third time he married a distant relative, Mrs. A. R. Wadsworth, who survived him.

Those associated with him in educational work will remember with pleasure how always ready he was to get equipment and to back up his associates in developments and new ideas. He also soon had an excellent working library and was strong for complete files of all the important publications. He carried the elective system and the division of courses into what looked like an extreme in the subdivision of courses, especially in a technical mining school, though a system of prerequisites diminished

the amount of electives practically. His announcements in Pennsylvania were certainly a curiosity.

Another excellent novelty was the four-term system in 1889 (no teacher teaching more than three terms), which Harper followed at Chicago in 1891-2. This made twelve terms in three years, and sixteen in four, and by cutting out all foreign languages time was thus found for what was really a remarkably strong course.

All this took up so much time that he was not able to devote much personal attention to the Michigan Geological Survey, of which he became director after the death of Charles E. Wright, father of F. E. Wright, through whom he was called to Michigan. They had laid out the work of the Survey on large lines.[4] Plat books for every township were opened, with a large scale map to locate every outcrop. From almost every specimen taken there was to be a thin section, and Hiram Cundy was kept grinding away all the time while the writer prepared descriptions of the thin sections. There were several thousand of these typewritten and corrected and ready for publication (but not worth publishing unless their significance was pointed out); and in the field a number of parties, largely directed by Seaman, were kept busy in systematic surveys both in the iron country and the copper country. But unfortunately work planned on so large a scale in a very complicated region, involving more than one controversy, overlapping work done by Van Hise, who had quite different ideas from Wadsworth, would naturally not come rapidly to publication. In the meantime the Board of Geological Survey, which was not the same as the Board of Control of the College of Mines, concluded that the old saying about no man serving two masters applied, got up a report of their own, in which reports not intended for publication were included, but also allowed Wadsworth to include a last report which, though without maps or illustrations, incorporated some of the results of the work under his charge.

On leaving the college he prepared a report for the Keweenaw Land Association (J. M. Longyear) on some of their lands near the Porcupine Mountains (and so far as I know this was the last of his geological work), but was soon, in 1901, called to the School of Mines at Pennsylvania State College, and then in 1908 to the University of Pittsburgh. In both places large orders for equipment, a larger number of courses, and an increased number of students followed, and there were stiffer requirements.

He retired in 1912 on the Carnegie Foundation, but did not cease to be interested in educational matters, as the following letter, the last I

[4] See Michigan Historical Magazine, 1923, No. 1.

received from him, testifies. Under date of September 24, 1917, he writes:

"For some time I have been preparing for publication an article relating to the colleges, schools, and departments of mines, metallurgy, and mining (economic) geology in the United States. Will you kindly give me your views as to the causes that lead to an increase or diminution from year to year of students and graduates in such schools? Should they be under the direction of their own special faculty or under a general engineering one—that is, civil, mechanical, electrical, and mining engineers and others? When two or more such schools exist in a State, if now independent, should they be united, or joined to some existent university, or if not united placed under the control of a single State educational board? Any suggestions for the benefit of such schools will be thankfully received."

His retirement was brightened by the fact that he was selected in the Harvard quinquennial catalogue as among her most distinguished sons, and also by the ovations received when he returned to the Michigan College of Mines in 1911 and 1916. On the former occasion President Drinker, of Lehigh, said:

"If I could win the love and respect of my students that your old students show for you, I would feel that I had accomplished the greatest and best work in the world."

Doctor Wadsworth passed from this life on April 21, 1921, and called forth the tribute by K. E. Davis, alumni secretary, in the Pitt Weekly of April 27, 1921, that is given below. That it seems appropriate to put this in the geological memoir is because as a geologist he was noted for the enemies he had made, and this shows the other side.

"The Mines School had been in existence but a few years, and had about a dozen students and a faculty of three or four. One of the members of the faculty was Ray P. Farrington, who had studied under Dr. Wadsworth at Penn State, where he had been Dean of the Mines School for many years. At the chapel exercise one morning—chapel was held daily those days—Farrington announced, 'W. U. P. has its "Mother" (referring to "Mother" Frost); now it is going to have a "Poppy." I refer to Dr. Wadsworth, just chosen Dean of the Mines School. "Poppy" is the idol of every one at Penn State. He is a regular fellow, and I miss my guess if the boys in this university won't go wild over him.'

"With this introduction every one awaited the coming of 'Poppy.' The writer has a vivid recollection of the first day he appeared on the campus. The faculty in those days was so small, compared to the present time, that the coming of a new 'prof' was a real event. Finally he arrived, and one glance at his face, with its ever-pleasant smile, was sufficient to prove to every one that Farrington was right. 'Poppy' *was* a regular fellow. He had a kind word for every one; he had a twinkle in his sharp eyes that showed he loved

a joke, and he knew how to make the boys study without having them know they were doing it at all.

"One of his famous possessions was a flowing white beard which gave him a very distinguished and dignified appearance. It was, indeed, something to be very proud of, and the students were very sorry when, a year or so later, he appeared 'sans beard.' No one could figure why he did it, and it created quite a sensation around the campus. George Baird, famous for his snatches of appropriate verse, penned some very witty lines regarding 'Poppy and his beard,' winding up with, 'G. G. O'Brien has rented the space.'

"'Poppy' chuckled when he heard of the commotion, and read George's lines, but he never explained why he had been so rash.

"Dr. Wadsworth was a wonderful teacher. He demanded the strictest discipline, and if he thought a fellow was 'soldiering' under him, he was relentless in his criticism. But if the student did his best, the 'old man' soon discovered it and gave him full credit. His 'exams' were always long and hard, but were unusually fair. A man had to know his subject to pass, and woe unto the one who tried to bluff! Every day's marks were carefully recorded and counted, with the tests, in the final record of the term.

"One of 'Poppy's' hobbies was to take 'the stones that the builders rejected' and shape them up. We refer to the 'flunkers' from other departments—many of them failures because they were in the wrong course, or because the faculty members of other schools didn't take the personal interest in them that 'Poppy' was willing to take. Numerous cases are recalled of apparently hopeless students who, transferred to the Mines School, made good under the wise guidance of 'Poppy.'

"One case in particular was impressed indelibly on our mind because we knew the principal very well and were in very close touch with the circumstances. A student in another department of the university was finding it 'tough sledding.' He was exceptionally good in practical work, but found the theoretical hard. He had gotten off to a bad start and just about lost heart. To make matters worse, his 'profs' didn't seem to understand him, and he was continually in wrong with them. Finally the word came that he was to be dropped from school. Some one suggested that he see 'Poppy' and try to switch to Mines. An interview with the good Doctor convinced the latter that the student had good stuff in him if it could be brought out, and he decided to give him a trial. Eventually he graduated with a fine record, and is today a very successful mining engineer. Naturally he has always been one of 'Poppy's' big boosters.

"Dr. Wadsworth was Dean of the Mines School from 1908 to 1912, retiring the latter year in favor of Dean H. B. Meller, one of his pupils. He has been Dean Emeritus of the school since that time, and has always taken an active interest in it. Until the last year, when ill health prevented, he made frequent trips to the campus to shake hands with old friends and greet new faces."

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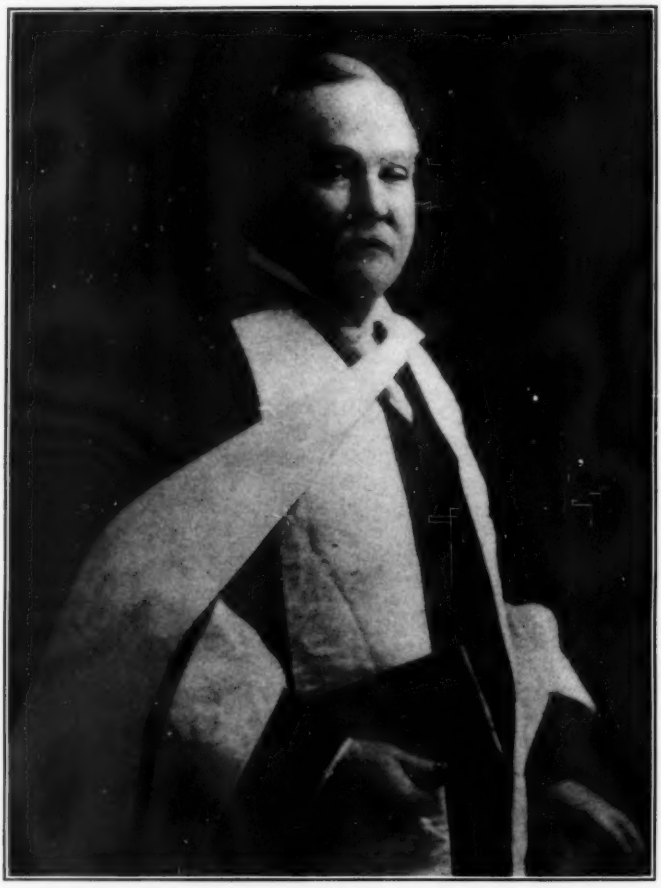

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MEMORIAL OF JOSEPH WILLIAM WINTHROP SPENCER [1]

BY EUGENE WESLEY SHAW

Joseph William Winthrop Spencer, B. S., M. A., Ph. D., LL. D., for more than forty years a prominent figure in geology, was born March 26, 1851, in Dundas, near the head of Lake Ontario, where he began his well known work on the history of the Great Lakes, this soon leading to the study of late crustal movements elsewhere, particularly as indicated by submarine valleys and features of the Antilles, Mexico, and Central America. He was an original Fellow of the Geological Society of America; a Fellow of the Geological Society of London, and a member of several other scientific and learned societies.

Spencer came from early Colonial stock. On one side he was a direct descendant in the ninth generation of John Winthrop, first Governor of Massachusetts. On the other side he came from the Curwen and Coe families, also originally of Massachusetts and Connecticut. His father, Joseph Spencer, was a miller and owned an extensive tract of land that included Spencer's Glen, with its waterfall, which became young Spencer's heritage in a double sense. Its power was turned into means for the necessities of life and education, and the problem of its cause and history

[1] Manuscript received by the Secretary of the Society January 16, 1924.

supplied the reagent that made known to him the kind of work to which his mind responded most actively and effectively.

At the time of his birth Dundas was a larger town than Hamilton, on the actual shore of the lake a few miles to the east and since grown to an important city; but Dundas still includes the residences of numerous old families, and several of its sons have become men of note, as, for example, Sir William Osler and Zebulon A. Lash, K. C. The Spencer house still stands at the mouth of the Glen—the main tributary of Dundas Valley—and Spencer was buried in the old family plot.

While Spencer was still an infant the father died and the surviving members of the family consisted of the mother and two sisters; the sisters are still living. His boyhood was thus spent in the country and in the village where his schooling began.

Spencer's endowment of scientific ability seems to have been first touched by J. Howard Hunter, a pioneer in nature study, who taught chemistry and other subjects in the Dundas High School. At fifteen Spencer outfitted a little chemical laboratory of his own and was becoming especially interested in the chemical characters of the minerals, rocks, and waters of the region in which he lived. At sixteen he was attempting quantitative analyses and all the while making short field trips, commonly with his teacher, who shared his enthusiasm. His appetite for natural science led him to memorize the illustrations of fossils in a textbook of geology.

About this time he became acquainted with Colonel C. C. Grant, a retired British officer, who was collecting and studying fossils about the head of Lake Ontario; also with D. F. A. Wilkins, discoverer of interglacial formations in Canada. By the time he graduated from high school he had decided to make geology his life work.

At twenty he matriculated at McGill, and at twenty-three received the degree of Bachelor of Science at that institution, with first-rank honors in natural science and Dufferin Medal. His professors at McGill included Dawson, Hunt and Billings, and Logan, already retired, added inspiration. He then obtained a position on the Geological Survey of Canada, but the following year decided to take a postgraduate course in Goettingen. Here he qualified for an M. A., and in 1877, at the age of twenty-six, received his degree of Ph. D.

His attachment for home and his interest in the local physiography brought him back to Dundas Valley, as they did repeatedly throughout his life. At this time he began a three-year period of service as science master at Hamilton Collegiate Institute, and, plunging into the controversies then active concerning glacial and stream erosion of valleys, he

gathered evidence which at that time seemed to him to indicate that Dundas Valley was once an outlet of Lake Erie.

From Hamilton he went to King's College, Nova Scotia, as professor of science, and in 1883, at the age of thirty-two, he was called to the chair of geology at the University of Missouri, where he built a museum, since burned. While at Hamilton he began the investigation of former shorelines of the lakes and the history of Niagara. First he mapped an old beach running from Dundas to Trenton, and then began recognizing various ancestors of the Great Lakes and giving them names that have since become common.

In 1888 he was appointed State Geologist of Georgia, and in 1893 he turned to problems relating to the late history of the Gulf of Mexico and surroundings and general studies of continental shelf physiography. These investigations occupied most of his time for the succeeding ten years.

In 1896 he married Kate Sinclair Thompson (whose father was a member of the firm of Thompson and Claxton), and she accompanied him on many of his later expeditions to the West Indies, Mexico, Central America, and Norway.

In 1905 the physiography of Niagara Falls was attracting an unusual amount of attention and the Canadian Government appointed Spencer a special commissioner to study them. This undertaking occupied his time for three years, during which he succeeded in sounding the river below the cataract, at the whirlpool, and at Queenston, and made borings to determine the location and form of the St. David's buried valley. As an outcome of this work we have the two well known reports, "The duration of Niagara Falls," and "The evolution of the Falls of Niagara."

In July, 1921, Spencer purchased a comfortable home in Toronto, where he planned to work up unpublished material from his notebooks, including some recent observations on the lower Saint Lawrence, which he considered important and to which he hoped to make additions. He had also planned to prepare a more popular volume on Niagara and had in mind several other pieces of work. In September he entered a hospital for a minor operation, but the difficulty proved to be more serious and he passed out October 9.

His personality and scientific work are both so well known, and particularly to geologists, that it would take a skilled writer to so describe them as to add to their value. He collected much evidence to show that the basins of the Great Lakes are old stream valleys, closed by drift and warpings and are not of glacial sculpture. He described submarine valleys and argued that they record profound changes in sealevel in rela-

tively recent time. His most gripping interest was in Niagara Falls. From distant countries he returned to them and spent part of almost every year in the region studying varying aspects and changes of form and attacking new problems or old problems in new ways.

The difficulties and hardships of travel in foreign and out of the way places brought him more joy than irritation. In Mexico and Central America, traveling by mule and oxcart, in Canada sleeping on the ground and living off the country, he accepted conditions as they arose. Even the questionings of country folk, and their suspicions of criminality and idiocy such as sometimes interfere a little with the field-work of geologists, only brought from him such replies as, "I am collecting *Polystornella striata-punctata,*" or, "I am cogitating on the mystical past."

He attended the Anglican Church, and in politics was a Democrat. He was intolerant of abuses, whether of a political, social, or private nature, and fought actively against the evils of bureaucracy. The under dog always had his sympathy. He was generous, appreciative of favors, and such a lover of animals that he would not own a dog because it would grieve while he was on field trips. A bystander once remarked that he gathered specimens as though they were jewels. He deeply enjoyed having congenial, intellectual people at his fireside. His sense of right and wrong, whether concerning a moral issue or scientific conclusion, was clear cut. He considered himself a slow writer, but in controversial correspondence he had a ready pen, and in the causes of justice or honor due he wrote and spoke with vigor. His more intimate scientific associates included Sir William Dawson, Robert Bell, J. P. Lesley, Friedhjof Nansen, James Geikie, J. D. Dana, W J McGee, J. W. Powell, Edw. Hull, E. H. Bonney, and Edmund Rabot.

He discovered the preglacial outlets from the Erie basin, and from the Huron basin, by way of Georgian Bay, to that of Ontario. Niagara was thus shown to be a modern river, and the upper Ohio a tributary of the Erie basin. He found that the upper lakes once discharged by the Trent Valley into the eastern end of Lake Ontario, in place of through Lake Erie, so that Niagara had only 15 per cent as much water as at present. He determined the location of the Falls when the Huron waters began to flow over them, the various heights of the Falls from the time of their birth (35 feet) through that when in three cascades they reached over 500 feet and were reduced again, and found that the level of Lake Ontario was once 180 feet lower than now. Outstanding features of his work are thus: his investigation of the history of the Great Lakes, "inaugurating in a great measure a new history" (Lesley); the discovery of the evolution of the Falls of Niagara, work which will "last and be

good for hundreds of years" (T. Russell), and "a monument worthy of a life's work" (F. B. Taylor); and his researches on earth-movements and great changes of level of land and sea, "whereby he may rightly claim to be the founder of a new branch of science, under the name of Sub-Oceanic Physiography" (Hull).

His contributions to geologic literature began to appear in 1875. The Bibliography of North America Geology has entries under his name averaging about three per year for the 47-year period of his productiveness. Of these entries 69, or about one-half, may be classified as dealing directly with the history of the Great Lakes, particularly Erie and Ontario; 25 with the Antilles, Mexico, and Central America, and 20 with continental shelves. Most of the remaining score of publications concern surficial geology, but include articles on exploratory, economic, areal, stratigraphic, and paleontologic subjects. Two have to do with the interpretation of gravity anomalies, two are in the French language, and the full range of subject-matter may be said to extend from graptolites to the hanging valleys of Scandinavia.

Spencer's writings are characterized by boldness, independence, and vigor. Driven to action by love of the science, he asked little aid and no quarter; none of his publications is a co-authorship product, and when satisfactory offerings of public or institutional aid were not forthcoming, he proceeded with his researches without financial help. He throve on opposition; antagonism was a fertilizer which only made him more fruitful. His bold strokes in turn stimulated others or stung them into action, causing them to evolve alternative hypotheses. Who shall say what progress has been due to such reactions?

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MEMORIAL OF ANTHONY WAYNE VOGDES [1]

BY E. T. DUMBLE

Anthony Wayne Vogdes, Brigadier-General, United States Army, and an Original Fellow of the Geological Society of America, died at his home in San Diego, California, February 8, 1923, in the eightieth year of his age.

General Vogdes was born at West Point, New York, April 23, 1843. He came of a family of soldiers. His father, General Israel Vogdes, who was a grandnephew of General Anthony Wayne, was a graduate of West Point, and was at that time connected with the academy as professor of mathematics. His mother, born Georgina Wayne Berard, was the daughter of the professor of French at the academy.

At the commencement of the Civil War he was a student of the Sanders Institute, in Philadelphia. He enlisted as a drummer boy in the Union Army and saw service throughout the entire war. In December, 1863, before he had reached his twenty-first birthday, he received his commission as second lieutenant of the 100th New York Infantry and later was brevetted captain and major of New York Volunteers "for gallantry and meritorious service during the war."

At the termination of the war he chose to remain in the army and was commissioned second lieutenant in the 4th United States Infantry. During 1868 and 1869 he was on duty guarding advanced construction camps of the Union Pacific Railway from attacks by Indians.

In 1875 he was transferred to the artillery, and in 1882 he graduated from the artillery school at Fortress Monroe and was promoted to captain. He served in Porto Rico during the Spanish-American War and later, as major and colonel, commanded the artillery districts of San Diego, California, and Key West, Florida.

He retired May 20, 1904, as brigadier-general. On his retirement he moved to San Diego to the home he had bought while stationed there.

[1] Manuscript received by the Secretary of the Society December 17, 1923.

At the time of his first enlistment an aunt gave him a Bible and a friend gave him a book on geology. He carried these two books with him during the whole of the war, and they were a strong influence in the molding of his character and the direction of his future life.

In December, 1867, he married Miss Ada A. Adams, of New York. At the time of his marriage the widow and daughter of Audubon became members of the Adams household and Lieutenant Vogdes assisted Dr. Adams in arranging the first volume of Audubon's works for publication.

Following this, while on duty with the Union Pacific at Fetterman, Wyoming, he began the collection of a geologic library and the study of geology.

As his education had been limited to his early studies in Philadelphia and those of the artillery school, he took up the further study of languages, including French, German, Italian, Spanish, and Norwegian, all of which he was able to read fluently. He thus became interested in philology and collected a small library on the subject.

Personally, he was modest and quiet; a lovable man, who made many friends and few enemies. He was patriotic and a keen student of American history. He was a member of the Loyal Legion and of the Sons of the American Revolution.

Soon after his return to San Diego he was elected President of the San Diego Society of Natural History, the second oldest scientific society in California, a position to which he was re-elected for fifteen years or more until finally allowed to retire at his own request.

He contributed to the Course of Science Applied to Military Art, published by the United States Artillery School at Fortress Monroe in 1884, Part IV, on Geology. This with two other short papers on local geology and his bibliographies of California geology form the bulk of his publications outside of those on trilobites.

His attention was apparently directed toward the trilobites from the beginning, and practically his whole life work beyond his military duties was devoted to that subject.

His field-work was practically limited to the areas surrounding his various posts, so that by far the greater part of the material for his collections was secured by correspondence. The assembling of this and of his library called for a large amount of letter writing, which was greatly augmented as years passed by his widening correspondence with paleontologists here and abroad. In this part of the work his wife was his amanuensis until her death, four years before his own, after which his niece, Mrs. Kendall, assumed the duty.

It was in this way that he got together his extensive collection of

trilobites and collected a library that is of especial value not only for its size, but because of the many old, rare, and beautiful paleontological works that it contains. Just before his death he received from Germany three volumes for which he had been searching for many years.

His first publications were descriptive of genera and species of trilobites. This was followed by the series of bibliographies of Paleozoic crustacea, which are his greatest contribution to science. The Genera and species of North American Carboniferous trilobites, published in 1888, may be regarded as the first of these, and was followed by a Catalogue of North American Paleozoic crustacea; a Bibliography of Paleozoic crustacea from 1698 to 1889; a Classed and annotated bibliography of the Paleozoic crustacea from 1698 to 1892, and Paleozoic crustacea, 1895 to 1917.

This brought the subject down to 1917, and at the time of his death he was working on the continuation of this bibliography to the beginning of 1923. This manuscript, practically complete, but not finally arranged, was turned over to his friend, Dr. Fred Baker, of Point Loma, California, who now has it about ready for the printer. It will be published in the very near future by the San Diego Society of Natural History.

He was an indefatigable and methodical worker. This is fully evidenced by the very complete card index he made in connection with his study of the trilobites and which contains more than 60,000 cards. On these he not only figured all the species by illustrations taken from publications or from his own camera lucida drawings, but endeavored to give complete data on them, either written or typed, so that it would be unnecessary to refer to publications for any desired information.

His library was further proof of this. Army life, with its periodic comings and goings, caused him to provide box containers for his books which, stood on end in a row, formed his book-cases when not traveling; and although this library grew to contain over 40,000 titles, he kept it in such order that he could at any time place his hand on the book or pamphlet he wanted.

His book-plate reads "Vogdesii et Amicorum," and this was literally true, for his books were always at the service of his friends.

In order to better preserve his books, he became an adept in the art of bookbinding, and most of his pamphlets have been assembled and bound by him into volumes. This interest continued to the very end of his life, and two days before his death he completed binding several books.

This library, as he stated before his death, contained everything which had ever been published on the geology and paleontology of California, and, besides this, complete sets of the proceedings of many national and

foreign scientific societies and governmental reports. In addition, there are great numbers of other books and papers in French, German, etcetera, bearing on his specialty. It thus has great value as a reference library not only on Paleozoic crustacea, but on other geologic subjects.

In his usual methodical manner he has noted the cost of each book on the corner of his book-plate, and from this it is estimated that the library cost him about $35,000. This library, left by will to his niece, Mrs. Stewart C. Kendall, of San Diego, was placed by her in the custody of the San Diego Scientific Library Association for the use of the people of San Diego. His large collection of trilobites was left to the San Diego Society of Natural History, and is installed with his library and card catalogue in the library building in Balboa Park.

In consideration of the scientific work that he did, it should be remembered that he was for many years located at army posts, away from all scientific centers or library facilities, and where he had full charge of his varied commands, the duties of which were discharged with a care for details and with a persistency that gained him a fine reputation as a soldier. Through all these busy years he devoted his leisure time to the special study of Paleozoic crustacea, built up his own library, and made of himself a scientific center, and it is the results of work done under such conditions that are shown by his contributions to the literature of the subject, his library, and his collections.

Thus, for a great many years, he lived two lives concurrently—that of a man of military science, in which he gained great credit, and that of a geologist whose works have become valuable books of reference for all workers in this branch of science.

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In addition to these works, General Vogdes left an uncompleted manuscript which will be published in the Transactions of the San Diego Society of Natural History in the very near future. There will be three distinct parts:

1. A continuation of the bibliography of Paleozoic crustacea down to January, 1923.
2. A list of the genera and subgenera of the Class Trilobitæ.
3. A monograph of the genus Cybele Loven.

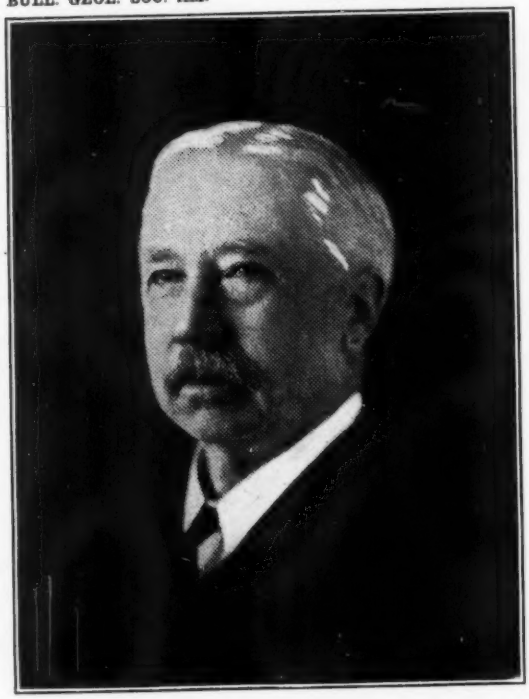
It will make about 175 pages of text and have two full-page plates.

MEMORIAL TRIBUTE TO RAPHAEL PUMPELLY [1]

BY BAILEY WILLIS

Raphael Pumpelly belonged to the great explorers. He was a Marco Polo, penetrating the Celestial Empire when it was still a closed land. He was a Humboldt, traveling in quest of an understanding of the world. He was a cosmopolitan, at ease with all men in any clime; and, like Roosevelt, he was a great, true-hearted American gentleman. Pumpelly was intensely human. His impulse was always kindly, his sympathies were quick, his heart was generous and deeply affectionate. He lived joyfully, scanning life keenly with his clear blue eye, meeting danger fearlessly, like the true Frank, the Barbarossa, that he was. Where adventure led, there Pumpelly followed—into Corsica to live with bandits; to Arizona in Apache days; before the Civil War to Japan and far into China, where he was chased as the Red Devil; across Siberia in the winter; and homeward through Russia. The wilds of our great Northwest attracted the explorer after his return, and yet Asia still claimed his interest. In his seventieth year he made a journey into the desert heart of the continent in search of ancient cities.

[1] In lieu of the usual memorial, which is being prepared, this brief tribute, read at the Washington meeting, is substituted.



R. C. Hills

As a scientist Pumpelly's interests were exceedingly broad. A mining engineer by training, he was a geologist by opportunity and because of the relations between geology and mining.

He has left to classic studies firm foundations for others to build on, in his work on Mount Greylock and his contributions to the interpretation of subaerial disintegration and soil origins. He also worked in hygiene. His major personal interest was, however, in ethnology—in the origin and history of the races of Asia, to which he made a notable contribution through exploration in the oases of Turkestan.

Pumpelly was one of those scientists whose greatest service was in inspiring others to solve problems which he suggested. His was a fertile mind, but he was impatient of the toil necessary to investigation. He always saw a great vista of knowledge stretching out before him, and with the explorer's instinct he strode forward toward the distant light. He welcomed fellow-explorers and he was ever ready to give them credit for their advances, claiming nothing for himself, even though, as was constantly the case, his thought had furnished the inspiration to their work.

So it happens that he will be remembered rather through the works he planned for others than by his own writings; but he will be remembered and honored as a great, genial, forceful leader by all with whom he came into touch.

MEMORIAL OF RICHARD CHARLES HILLS [1]

BY R. D. GEORGE

Richard Charles Hills was born in Ewhurst, Surrey, England, February 5, 1848. He died in Denver, Colorado, August 14, 1923.

He received an elementary education in a common school in London, and in 1865, at the age of seventeen, came to the United States. The western frontiers had an irresistible attraction for him and within two years he found his way to the gold fields of California. During the first fifteen years of his life in America he visited most of the active mining camps of California, Idaho, Nevada, Arizona, New Mexico, and Colorado. But he was not merely a wanderer; he was primarily a traveling student, supplementing close observation and practical experience with an intensive study of higher mathematics, astronomy, physics, and assaying.

His reading and study were by no means confined to the scientific fields. He found time to make the acquaintance of the best literary and historical authors.

[1] Manuscript received by the Secretary of the Society February 12, 1924.

After permanently locating in Colorado in 1880, and selecting Denver as headquarters, he settled down to four years of laboratory, library, and field study of chemistry, mineralogy, and geology. About this time he began to contribute articles and notes to various scientific publications, such as the American Journal of Science and the Proceedings of the Colorado Scientific Society. The number of such contributions and other writings is such that only a selection can be made for the bibliography accompanying this sketch.

He became a member of the Colorado Scientific Society at its first regular meeting, January 2, 1883, and for forty years was an active, interested, and inspiring member, carrying cheerfully his full share of official duties and responsibilities. He was twice President of the Society—1889 and 1891—and was made an honorary Fellow in 1905. He was elected a Fellow of the Geological Society of London in 1884 and of the Geological Society of America in 1894.

The scope of his work, like that of his reading, was very wide. It covered every phase of mining and mine operation, both in the metals and coal. The best testimony to his rank as a geologist is the series of United States Geologic Atlas folios of Elmoro, Spanish Peaks, and Walsenburg, and his contributions to the Proceedings of the Colorado Scientific Society.

For over twenty years he was geological expert for the Colorado Fuel and Iron Company; and for an almost equal time he served the Victor Fuel Company, the American Fuel Company, and the Northern Coal and Coke Company not only as geologist, but as expert in their coking, briqueting, and other technical operations.

His skill was also in demand as an oil geologist, in which capacity he served chiefly the United and Continental companies.

It is not alone because of his more strictly business and professional achievements that he will be remembered; his extraordinary and tireless work as curator of the Denver City-Park Museum has made it an enduring monument to his memory. Through it he will long speak and reveal to the people, young and old, the secrets, the beauties, the wonders of the sciences he loved and did so much to promote.

Comparatively few men, unaided, have attained such a wide knowledge of the sciences, such an appreciative acquaintance with literature, philosophy, and the arts in a lifetime of such constant and often strenuous labor.

An intimate friend has said:

"To him time was not money. It was opportunity to achieve something for the good of the race. He wanted money for the joy he found in giving it

away. This earnest man was the kindest, gentlest, most generous I have ever known."

No words of mine can so adequately portray the man as the closing paragraph of a brief but comprehensive philosophical thesis written by Mr. Hills a short time before his death (unpublished):

"I regard Jesus Christ as the apotheosis of an ideal man. Whether divine or not, his teachings and beauty of expression were divine. He was the paragon in all that makes for righteousness, happiness, love, and truth. His unapproachable life on earth commands my most profound admiration. Well might the stern Roman, Pontius Pilate, exclaim, 'What evil hath he done?' 'I find no fault in him.' His sublime utterances cover all the depths and shoals of human nature. For these reasons I accept him as my guiding star, as the mirror of my every-day life—as my model in all things."

Valuable assistance in compiling this data has been rendered by Mr. Olney Newell, of Denver.

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MEMORIAL OF HORACE VAUGHN WINCHELL

BY JAMES F. KEMP

Rarely in the history of American geologists has a son followed in his father's footsteps. Still more rarely have two. Yet Newton H. Winchell, past President of this Society, had the unique experience of seeing both his sons choose geology for their calling and both attain distinction in their father's profession. In memory of Horace Vaughn Winchell, his oldest child and older son this tribute has been prepared.

Horace Vaughn Winchell was of English ancestry. Robert Winchell, the progenitor of the family, settled in Windsor, Connecticut, in 1635. The descendants of Robert spread in time to the border of New York with Connecticut and Massachusetts, where in the town of Northeast, in Dutchess County, New York, both the brothers Alexander and Newton Horace Winchell were born, and from it set out in the fifties of the past century for the University of Michigan. The two brothers, in their geological work, followed the pioneer and explorer's period in the region of the Great Lakes and upper Mississippi Valley. They became in time State Geologists respectively of Michigan and Minnesota and professors as well in the corresponding State universities. Both were not only scientific men, but teachers and citizens of exceptional public spirit. They were, moreover, men of musical tastes and gifts, of open, frank, and generous character and of profound religious nature. By direct inheritance the subject of this memorial gained these characteristics and they bound his friends to him with ties of unbreakable strength.

While Newton Winchell was still alternately teaching school and completing the requirements for his university degree, Horace Vaughn, his oldest child, was born in Galesburg, Michigan, November 1, 1865, at the home of his mother, whose maiden name was Charlotte Sophia Imus and who had been married to his father in Galesburg, August 24, 1864. After various places of residence incident to teaching in Michigan and work on the Ohio Geological Survey, the family moved to Minneapolis in 1872, when Newton Winchell became State Geologist and professor in the State University.

In Minneapolis, Horace, the son, grew up from his seventh year, until

Sincerely
Horace P. Winchell

he entered the University of Michigan, where he graduated in 1889. In the university he devoted himself especially to the natural sciences, and took much work with his uncle, Prof. Alexander Winchell. On graduating he returned to Minnesota, and for the next nine years was either engaged on the State Survey in the iron ranges or else in private practice in the applications of geology to the problems in mining and engineering. Horace Winchell's graduation just preceded the discovery and early development of the Mesabi Range, so that shortly after his work on the Minnesota State Survey began he was assigned to the study of this new and promising source of iron ore. His father, the State Geologist, was alive to the importance of the indications shown by the early pits. Accordingly, the two, in close association, prepared Bulletin VI of the Survey, a volume of 430 pages, published in 1891 and entitled "The iron ores of Minnesota." The appended bibliography will show, however, that for four years earlier the junior author had been studying the parent strata of the ores and reflecting upon the interesting subject of their origin.

The Mesabi, so-called "Range," was then a rather unaccentuated, deeply drift-covered area, clothed in pine forest. Only by the aid of the exploring pits was the elaboration of the geology possible. When these handicaps are appreciated, we realize all the more strongly that the two authors did an extremely creditable piece of work. Two years later a report upon the Mesabi Range alone was issued by Horace Winchell and was widely reprinted, appearing, among other places, in the Transactions of the American Institute of Mining Engineers, volume XXI, pages 644-686, 1893. This report had a very important influence in the development of what has since proved to be the most productive American iron ore area. Its geological sections were copied in many other places. Even as early as 1889 Horace Winchell, in association with his father, had reached a conclusion for the origin of the cherty iron carbonates of the Lake Superior region, which involved chemical precipitation from oceanic waters. The citation is given in the appended bibliography, and is so striking a forerunner of the views advocated today as to seem prophetic.

There is one additional feature of Bulletin VI which deserves comment. It contains a bibliography of the literature on iron ores which goes back over centuries to the earliest records available to its compilers. Horace Winchell thus became interested in the literature of mining geology, and as years passed and journeys to Europe became possible he ransacked the bookstores on both sides of the Atlantic for works ancient and modern. Thus he accumulated a notable library in which are many rare treasures not easily accessible elsewhere.

The hard times of 1893 followed the early developments on the Mesabi Range and depressed the mining industry with great resulting changes in ownership. Horace Winchell, as specialist on the geological side, and F. F. Sharpless (now Secretary of the American Institute of Mining and Metallurgical Engineers), as specialist on the analytical side, formed a partnership for two years; but dwindling engagements in the Lake Superior region and calls to the West led more and more to work in that area and the partnership dissolved.

In 1898 Horace Winchell became geologist for the Anaconda Copper Mining Company and remained on its staff eight years. They were years of important service to the industry and to geology. A geological staff was established; a system of large scale and superposable, transparent, geological maps by individual levels was adopted, with many accompanying vertical sections, and thus records were afforded which, for guiding development, were much more serviceable than the ordinary engineer's maps of workings. The system has since spread far and wide and has been an exceedingly valuable contribution to mining. From experience and observation of the cherty iron carbonates of Lake Superior, whose alteration by surface waters produced the soft ores, Horace Winchell was led to observe similar reactions in the copper veins of Butte and to reach the conclusion that at least a part of the chalcocite of the upper levels might be or actually was secondary. Assisted by C. F. Tolman, Jr., as chemist, experiments were instituted in the laboratory to artificially reproduce the copper glance. After many unsuccessful attempts, extending over months of time, it was found that in the presence of sulphur dioxide chalcocite readily precipitated. These experiments were finally published in the Bulletin of this Society in 1903, after being held up, as were other important observations of Horace Winchell, by the bitterly contested apex suits of this period in Butte. Meantime, also, in the Bulletin of this Society, W. H. Weed had published in volume XI, pages 179-206, 1900, his paper on "Enrichment of veins by later metallic sulphides," and before the American Institute of Mining Engineers the following year S. F. Emmons had presented "The secondary enrichment of ore deposits" (Transactions, volume XXX, pages 177-217). Secondary enrichment of copper ores at Ducktown, Tennessee, was, however, well known at a period even antedating Whitney's "Metallic wealth of the United States" (1854), as can be seen from the illustrations in this work. While there was a prevalent idea that the black ores were, at least in part, the black oxide, melaconite, yet the smelters at Swansea, to whom they were shipped, could have had no illusions of their identity when they came to adjust furnace charges. But the great revival of interest in

secondary enrichment of copper ores was inaugurated at Butte just as the last century closed; and was also given great impetus by the rise of the so-called "porphyry coppers" shortly after.

In the closing year of the past century the preparation of the famous Colusa-Parrot case-at-law revealed to Horace Winchell the existence of the northwest series of fault veins, often called the Blue Vein series, which were later in age than the Anaconda vein and which faulted the latter. A very important structural addition was thus made to our knowledge of this famous mining center. Several times in recent years the writer has talked over these early days in Butte with Horace Winchell and has learned of his struggles to convince his chief, Marcus Daly, and other operators even of the existence of faults in the mines—an experience which, viewed from the vantage point of today, is highly diverting.

In 1906 Horace Winchell resigned as chief geologist of the Amalgamated Company, which included the Anaconda, and was succeeded by Reno H. Sales, of his staff. He became geologist for the Northern Pacific Railroad, and throughout its tributary territory made many careful studies and estimates. Two years were devoted to this work, and then an independent office was established in Minneapolis for examinations, consulting work, and the preparation and presentation of cases in litigation. In all of these applications of geology to the development of industrial enterprises or the settlement of ownership claims Horace Winchell had constant engagements. He made ten trips to Alaska, on one of which he was shipwrecked on the ill-fated steamship *Ohio* and lost all of his equipment. He did important work in Mexico and acquired experience in South America. To Europe he went many times, participating in the Eleventh International Geological Congress in Sweden in 1910. He was sent to Russia in 1917, and after a reconnaissance in the Caucasus was in Petrograd during the revolution which overturned the Kerensky government. From the windows of the hotel he, with Mrs. Winchell, watched the street fighting. Eventually both safely returned to America over Siberia and the Pacific.

During all his years of active professional work Horace Winchell maintained a keen and predominant interest in geology as such. His habit of mind and tastes were thoroughly scientific and his ideals of contributing to knowledge and of opening new resources for the use of humanity were high and strong. Of the hostile and critical attitude of many small scientific men to service of this sort he sometimes spoke with a little bitterness, and he felt it deeply that what he justly regarded as a large service to humanity should sometimes suffer in comparison with measuring and counting the ribs on the dorsal valves of spirifers. Feel-

ings of this sort, however, were not permitted to linger long or find a place in his cheerful and forward-facing mind and were habitually dismissed with his favorite saying, "Forget it."

The magazine, the American Geologist, was established in 1888 largely by the efforts of his father. It continued through thirty-six semi-annual volumes and had, especially in its later years, a hard financial struggle. Indeed, only the financial help generously given by Horace Winchell made it possible, and when its issue ceased, in December, 1905, the stock of back numbers, copyrights, and other things of the kind became his property. He was one of the original supporters of the magazine Economic Geology when it was inaugurated in January, 1906, and he transferred his rights in the American Geologist to Economic Geology, on the title page of whose first complete volume is printed the statement that it forms volume XXXVII of the American Geologist. Beginning with volume IV, he became one of the eight associate editors, but retired with the completion of volume VIII in favor of Waldemar Lindgren, who had been called to the Massachusetts Institute of Technology. With S. F. Emmons and the writer, Horace Winchell formed, from 1896 on, the three American associate editors of the Zeitschrift für praktische Geologie, which was begun in Berlin in 1893. After the death of Dr. Emmons, the other two continued in this relation until the United States entered the World War, destroying these pleasant international relationships with so many others.

With a number of old friends of T. A. Rickard, he was one of the special contributors on the editorial staff of the Mining and Scientific Press in 1908. Horace Winchell wrote with marked fluency and in charming literary style. He was no less at home in descriptions of travel and of striking incidents in professional life than in science, as witness his delightful contribution to the Atlantic Monthly in 1923, describing his early endeavor to acquire an Iowa meteorite.

In the last ten or fifteen years of his life, his most serious contribution to public-spirited work was his advocacy of the revision of the United States law governing mining claims and the ownership of mineral properties in the public domain. Through the Mining and Metallurgical Society of America, which began a discussion and agitation for this reform in its early years and later in the American Institute of Mining Engineers, he gave generously of time and effort to forward it. With many others he hoped, by simplifying the statute, to eliminate from future locations the expensive litigation which now attends extralateral rights to "veins, lodes, and ledges." Likewise, with many others, he hoped to bring under review of the courts the autocratic, confiscatory

power now possessed by the General Land Office over coal and similar lands. Horace Winchell's wide experience in all these matters gave exceptional force to his words. In this cause, as in all others affecting the public good, he gave freely and generously.

Horace Winchell was one of the ninety-eight original Fellows of the Geological Society of America, having responded to the first call for members in 1889. Both his father and his uncle, Prof. Alexander Winchell, were among the thirteen who met at Ithaca, New York, December 27, 1888, and organized the Society. Alexander Winchell is generally considered to be the Father of the Society and was its third President, following James Hall and James D. Dana. Newton H. Winchell was fifteenth President, in 1902. Horace was thus peculiarly the child of the Society. He became a member of the American Institute of Mining Engineers in 1892, and was a Manager, 1901-03; Vice-President, 1909-10, and President, 1919, following Herbert Hoover. In the Mining and Metallurgical Society of America he was Councilor for the Lake Superior District, 1910-14 and 1920-23. With several foreign societies devoted to geology and mining he was also connected.

Horace Winchell was a loyal friend, a delightful companion, and a strong and helpful character. In his social relations he had a marked and characteristic charm. He was in earlier years a whist player of national reputation, having represented his home city, Minneapolis, in contests for national championships. He was a golfer of exceptional skill and turned to the links for his fresh air and recreation. In later years he well knew that some difficulty with his heart made necessary great care against overexertion. Twice he had taken the cure at Bad Nauheim to his great benefit. This trouble, however, asserted itself alarmingly last summer and proved irresistible on July 28.

Horace Winchell was married in 1890, the year following his graduation, to Ida Belle, daughter of Prof. Alexander Winchell. To Mrs. Winchell, now resident in Los Angeles, the profound sympathy of the Geological Society of America goes out.

In the preparation of this memorial the writer has drawn on an intimate friendship of many years and has been greatly aided by Prof. A. N. Winchell, by whom the bibliography, except for one or two additions, was brought together. It has already appeared in the Pan-American Geologist for October, 1923, pages 175-180, accompanying a memorial by C. R. Keyes. Of special interest is the interview by T. A. Rickard, published in the Mining and Scientific Press, February, 1919, pages 211-219, which is essentially a brief autobiography. It has been since reproduced in a volume of similar interviews with leading members of the mining

and engineering profession—all taken from the same journal. A short memorial sketch by John P. Gray, together with a number of personal tributes, appeared in Mining and Metallurgy, September, 1923, pages 463-464, but the extended memorial for the American Institute of Mining and Metallurgical Engineers is in preparation by John A. Blair, long legal counsellor of the Institute and Horace Winchell's college chum.

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1920. Rapid formation of lead ore. Discussion: Transactions of the American Institute of Mining Engineers, volume LXIII, pages 317-321.

[The litigation geologist protests.] Engineering and Mining Journal, volume CX, pages 192-193.

[Address at New York.] Engineering and Mining Journal, volume CIX, pages 500-501.

[The reconciliation of science and law.] Engineering and Mining Journal, volume CX, pages 1159-1162.

1921. [A defense of apex procedure.] Engineering and Mining Journal, volume CXII, pages 163-164.

Geology of Pachuca and El Oro, Mexico. Transactions of the American Institute of Mining Engineers, volume LXVI (1922), pages 27-41.

Recent Supreme Court interpretations of mining law. Engineering and Mining Journal, volume CXI, pages 938-939.

1922. [Testimony on mining law revision.] Engineering and Mining Journal, volume CXIII, pages 1063, 1108.

Mining methods at the Ashio copper mine. Discussion: Transactions of the American Institute of Mining Engineers, volume LXIII, pages 317, 321.

1923. A meteoric career. Atlantic Monthly, volume CXXXI, pages 779-786.

PAN-PACIFIC SCIENCE CONGRESS

Attention was called by the President to the fact that delegates were appointed to several important scientific gatherings in the course of the year, one of which was the Pan-Pacific Science Congress, held in Australia. Of the delegates appointed by the Society to this Congress, the following had been in attendance: E. O. Hovey, T. Wayland Vaughan, William H. Hobbs, N. M. Fenneman, Alfred H. Brooks, and Herbert E. Gregory.

The following account of the meetings and a statement of the problems discussed in the Congress were presented by E. O. Hovey:

As one of your delegates, it was my esteemed privilege to represent the Geological Society of America at the Second Pan-Pacific Science Congress, which met in Melbourne and Sydney, Australia, last August and September. I brought away with me a picture of a wonderful country, interesting from its geology, its paleontology, its scenery, its botany, its fauna, and its human inhabitants, both aboriginal and present. All were enhanced by the great hospitality of its people, who endeavored to show the visiting scientists from all over the world the natural features of the land and the efforts which are being made to make the best use of the country.

There were present about eighty overseas delegates, covering the following countries: Great Britain, Canada, United States, Japan, Burma, Malay States, Dutch East Indies, Philippines, Papua, Tahiti, Fiji, New Zealand, India, and

South Africa. In Melbourne there were about two hundred local members of the Congress and in Sydney about five hundred.

The address of welcome at Melbourne was given by Sir David Forster, Governor-General of the Commonwealth, who emphasized the scientific objects of the convention, and also the general good will and mutual understanding which were sure to arise from the sessions. Sir David Orme Masson, President of the Australian National Research Council and President of the Congress, gave the inaugural address, which was responded to by Prof. Sir T. Edgeworth David, of Sydney University.

For the delegates Prof. Count Sakurai replied, saying in part: "Never before has Japan sent so large a delegation of scientific men to any congress either in America or Europe. That fact shows how deeply interested Japan is in the work of the Congress, and also the strong brotherly feelings her scientists have toward their Australian colleagues. I hope that the Congress will tend to dispel misunderstandings, if there are any, and will promote the well-being of the peoples of our respective countries, and that our nations will thus learn to respect and trust one another. The aim of science is the pursuit of truth and its application to human welfare, and to scientists united in that common aim all thought of enmity, whether arising from differences of race or religion, is absolutely hideous."

The Congress divided itself into sixteen sections for the reading of papers and the transaction of business. There was a wealth of papers on the geological phases of Pacific matters. One outstanding subject discussed in these was the unity of the Pacific as a geographical feature whose framework had been determined by earth folds resulting from a common origin and whose crust movement had affected geography, climate, economic conditions, and plant and animal distribution. The papers gave much time to a discussion of the origin and value of the ore deposits of the Pacific, the age and origin of the more important coal measures, the oil and artesian water resources, and the stratigraphy of the younger rocks around the basin. The varied problems that were considered by the geologists also included the effects of ice ages, igneous activity, and the nature and origin and distribution of coral reefs and islands. One session was devoted to a consideration of the status of geological surveys in all the lands bordering the Pacific, which brought out the relatively small proportion of land regarding which there is much accurate geological information. The visiting geologists, especially those from America, laid stress upon the necessity of the preparation of topographical maps as a basis for geological work. The absence of such maps in Australia, New Zealand, and South America was particularly deplored.

Seismology naturally received much attention from the delegates, and under the lead of Professor Omori, chairman of the Section, important discussions were held. His statement that he was now able to foretell within limits the imminence of an eruption or earthquake was lamentably emphasized during the Sydney session of the Congress by the occurrence of the terrible earthquake at Yokohama on September 1.

The inaugural address at Sydney was given by Sir Walter Davidson, whose closing sentences are worthy of repetition here: "And, at the end, while we wonder that science and art and good will, advancing hand in hand, can in-

voke blessings, spiritual, mental, and material, on our assembled nations, yet always in the deep recesses of our hearts we wonder—nay, we hope and, indeed, we do believe—that meetings such as ours will exorcise the demons of jealousy and unrest, and lay them in a limbo with the brutalities and follies of the past. Nationhood—the pride of race—is a glory only so long as its inspiration is actuated by peace on earth and good will among men."

The last day of the Congress was occupied with the general session, in which were discussed and adopted a considerable number of resolutions and recommendations with reference to the promotion of further scientific work. All of these resolutions were handed to the Australian National Research Council, as the executive body of the present Congress, for presentation to the respective governments or other authorities to whom they were addressed.

The third meeting of the Pan-Pacific Science Congress is to be held in Japan in 1926, by acceptance of the cordial invitation given by the representatives of the Imperial Government, in spite of the news received on the day the invitation was read of the devastating earthquake which had laid waste so large a portion of their fair land.

JOSEPH LEIDY COMMEMORATIVE MEETING

President White called attention to the Joseph Leidy Commemorative Meeting, which he attended as official representative of the Society; and made the following remarks:

A celebration of the centenary of the birth of Joseph Leidy, distinguished vertebrate paleontologist and naturalist of Philadelphia, was held in that city Thursday, December 6, 1923, under the auspices of the Academy of Natural Sciences of Philadelphia, the College of Physicians of Philadelphia, the National Academy of Sciences, the Smithsonian Institution, and numerous other scientific and educational institutions of the United States. Delegates from most of the learned societies of the country were present. The Geological Society of America was represented at the meeting by Henry Fairfield Osborn, W. B. Scott, R. A. F. Penrose, Jr., and David White. Doctor Penrose, President of the Academy of Natural Sciences of Philadelphia, was the honorary chairman of the meeting. Three sessions were held, at which were reviewed (1) Leidy's zoological work and his influence upon scientific thought and development, (2) his paleontological, botanical, and mineralogical work, and (3) his character and his records as anatomist and teacher of physicians and surgeons and his impress on medical science and thought.

An address on Leidy's "Paleontological and Geological Work" was delivered by Dr. William B. Scott at the afternoon session, and "The Joseph Leidy Lecture in Science," by Prof. Henry Fairfield Osborn, was the principal address of the evening program. The program constituted a most interesting, stimulating, and profitable review of the beginnings and early history of vertebrate paleontology in America, with side lights on the zoology and botany of the period. In all of these Leidy played an important part as pioneer, in the days when vertebrate paleontology recruited its first devotees from the ranks of surgeons and physicians.

A fascinating feature of the meeting was the exhibit of *Leidyana*, which embraced many original drawings faithfully executed by his own hand to accompany his numerous papers on invertebrate zoology. The review of Leidy's work in botany formed an interesting chapter of systematic and ecological investigations, the results of which were never published, but all of which pictured Leidy as a leading representative of the early generation of all-round naturalists in America. Throughout there ran, also, the portrayal of an unflaggingly enthusiastic and industrious scientist of gentle, tolerant, generous, and altogether lovable character.

QUESTION OF A SPRING MEETING

President White remarked on the difficulty of attending meetings that come in the holiday season, and the additional difficulty that arises from the fact that weather conditions are practically always unfavorable at that time for field excursions that might otherwise be planned in connection with the meetings of the Society. With a view to some improvement in these respects, he suggested for future consideration the question of a spring meeting for the presentation of papers and for excursions.

At 10.30 the papers listed for the Thursday morning session were called for.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

BASIN STRUCTURES IN MONGOLIA

BY CHARLES P. BERKEY AND FREDERICK K. MORRIS

(*Abstract*)

The Gobi is a gently down-warped broad basin, the easternmost of a chain of great inclosed, warped lowlands which lie across the middle of Asia from the Caspian to the Amur. Within the Gobi are minor lowlands called "Talas," bounded by gentle warp-divides or by mountain ranges. Within each tala are still smaller basins filled with continental sediments, ranging from Comanchean to Pliocene. They rest on a floor of low, mature relief composed of strongly deformed older rocks, pre-Cambrian to Jurassic.

Two types of basin are recognized, though no sharp demarcation can be drawn between them: (1) faulted or piedmont basins, which are more disturbed, carry thicker sediments, and represent more geologic periods, and (2) warped or plains-basins, which are shallower and contain the sediments of fewer periods than do the faulted basins. Areas of basins vary from 30 to 10,000 square miles, and thickness varies between 200 and 5,000 feet. The succession of formations is not complete within any one basin, and the gaps in the column show (1) that warping to form basins happened at different times in different places; (2) that warping once started in a given basin was not continuous, but intermittent; and (3) that the locus of warping shifted even within a single large basin. In the Altai piedmont, the shift or canting

of the basin was toward the mountain, correlating the deepening of the basin with the mountain-building, the younger sediments being found nearer the mountains. Thus periods of basin-sedimentation correspond with periods of mountain uplift. The upwarp in the Altai region commenced in Comanchean time. After a moderate post-Cretaceous disturbance came quiescence, followed throughout Tertiary time by intermittent warping, which culminated in large faulting in the late Pliocene.

Presented in abstract extemporaneously by both authors.

DISCUSSION

Prof. ANDREW C. LAWSON: The structural trough at the base of the range, now deeply filled with deposits derived from the erosion of the mountain, is in accordance with what might be expected from the operation of isostatic compensation.

Prof. CHARLES SCHUCHERT: Whatever the students of physical geology may say about the splendid work of these authors, I rise to congratulate the speakers on the immense amount of dated stratigraphic and physiographic knowledge they have brought out of interior Asia. Truly their work is one of the most important advances in historical geology made during this century.

Remarks were also made by Mr. Arthur Keith, with reply by the senior author.

EARTH MOVEMENTS IN CALIFORNIA AS DISCLOSED BY TRIANGULATION

BY WILLIAM BOWIE

(*Abstract*)

Thirty years or more ago the United States Coast and Geodetic Survey completed precise triangulation along the Coast Range of California and the western end of the transcontinental arc.

In 1906 it was realized that a reoccupation of the old triangulation stations in the vicinity of San Francisco would furnish a means of detecting the order of magnitude and the direction of the movements which resulted in the earthquake of that year. A number of the old triangulation stations were reoccupied in 1906 and the new positions for the stations were computed. It was found that marked horizontal movements had taken place since the early work had been executed.

Realizing the importance of precise triangulation as a means of detecting the stability of the earth's crust, the Committee on Seismic Investigations of the Carnegie Institution of Washington requested the Director of the United States Coast and Geodetic Survey to make an extensive investigation in California, with funds provided by Congress, and field work was done during the seasons of 1922 and 1923. Preliminary values for movements of peaks on which the stations were located are now available.

In the adjustment of the new observations, the geographic positions of Mount Lola and Round Top, two mountain peaks of the Sierra Nevadas to the eastward of San Francisco, were held fixed.

The differences in the positions of the stations to the eastward of the line joining Mount Diablo and Mocho are so small as to indicate practically no earth movements; but from Ross Mountain, the most northern station in the investigation, to the stations San Luis Obispo and San José, the most southern stations, there has been considerable movement with wide variation in distance and direction. In general, the movement to the southwest of the San Andreas fault has been to the northward, while the trend to the northeast of the fault has been southward; but there are a number of exceptions to this rule. Notable ones are the Point Reyes lighthouse and Farallones lighthouse. At the former the movement has been 11½ feet to the northward, while at the latter the movement was 5 feet to the southward. At Loma Prieta Peak the movement was southeast about 7 feet, while at Castle Mount the movement was northward, slightly over 9 feet. The largest movement for any one of the stations involved in the investigations was at San José Peak, where it was nearly 16 feet to the northward.

Field work will be continued during 1924.

Presented in abstract extemporaneously.

Discussion

Mr. Arthur Keith: The paper to be presented by Doctor Crosby on "Keystone faults" offers a suggestion as to a means of holding or locking the differential movements in earthquakes. His theory suggests that wedge-shaped blocks drop into slight spaces caused during earthquake shocks and thus fix an extension of the crust.

Author's reply to Mr. Keith: I do not quite see how a wedge-shaped block, dropping into open spaces caused during earthquakes, could fix an extension of the earth's crust. The opening of the earth in the form of a fissure during an earthquake shock is very small in width, and it is reasonably certain that there would be no wedge-shaped block dropping into the fissure. There may be some opening and closing of a fissure during an earthquake shock, but this seems to be rather improbable. The fissure is the result of a straining of the earth's crust beyond elastic limits, and it is reasonably certain that it is very local in extent. Therefore, even though a wedge should settle down into the fissure, it would not have any effect in increasing the circumference of the earth.

Prof. L. C. Graton asked Mr. Bowie as to the advances in precision of present measurements, with respect to methods, instruments, and the personal equation, in contrast with measurements made during the period of comparison, ranging over 20, 30, and even 50 years; also as to the absolute degree of precision of present measurements as an index of their availability for comparison with measurements in future years, when it may be assumed still greater accuracy will have been attained.

Author's reply to Professor Graton: Some noted advances have been made in theodolites during the past fifty years, with which the horizontal angles in triangulation are measured. This does not mean, however, that the values of the observed angles today are any better than they were, say, 40 or 50 years ago. There is a limit to the accuracy which should be obtained in triangulation which is dependent on the cost and time elements. The accuracy is that

represented by the closing error of triangles which, for precise work, is approximately one inch on an average. It is felt that this accuracy will meet all the scientific and practical requirements. We are able today to secure the necessary degree of refinement with fewer observations than were used years ago when the theodolites were not so perfect. The essential thing in a theodolite, to secure great accuracy, is the degree of perfection of the graduation of the horizontal circle. It is probable that observations in the future will be more accurate for single measures, for undoubtedly instruments of precision will be continually improved. But it is probable that the number of observations will be reduced in order to secure a greater quantity of results with the required degree of accuracy, rather than to continue to make as many observations as we do now. As far as the observations to determine vertical movements of the surface are concerned, it may be said that precise leveling, as done today, will meet all of the scientific requirements of the seismologist. It is difficult to see how the instrument and methods now employed in the United States Coast and Geodetic Survey for its precise leveling could be materially improved.

Prof. ANDREW C. LAWSON: The work of the Coast and Geodetic Survey, the results of which have just been reported to the Society, are of great importance to geology, inasmuch as it gives us accurate measurements of horizontal displacements of the earth's crust, referable to the strain creep which precedes faulting and earthquakes. It is a quantitative study of earth movement in progress.

Brief remarks were also made by Prof. A. M. Bateman, with reply by the author.

MOUNTAIN-BUILDING WITHOUT LOSS OF ISOSTATIC EQUILIBRIUM

BY FRANCIS P. SHEPARD[1]

(*Abstract*)

In constructing theories concerning the formation of mountain ranges it seems unwise to disregard two ideas which are as well established as are those of isostatic equilibrium of the crust and crustal shortening due to a shrinking interior. While it is commonly supposed that these two ideas are incompatible, such a supposition is not altogether warranted.

The piling up of the earth's crust by lateral compression can be accomplished without overburdening the crust, if there is a decrease in density of the underlying material such as would be caused by the formation of a magma beneath a range. The relief of burden on the interior, produced by the arching of the crust, would favor the formation of molten rock.

Presented in abstract extemporaneously.

DISCUSSION

Mr. WILLIAM BOWIE: I wish to commend Doctor Shepard for his efforts to harmonize the theory of isostasy with some of the older theories dealing with

[1] Introduced by William Bowie.

the formation of mountains. The facts of isostasy seem to be well established and they should be taken into consideration in formulating any theory as to why great changes in elevation of the earth's crust take place. Doctor Shepard has not made it clear as to how regionally acting, compressive, horizontal forces can initiate a syncline; and, after the accumulation in the syncline of thousands of feet of sediments, make the strata reverse their direction of movement and thus form an uplift.

Prof. W. H. Hobbs: I would like to call Doctor Shepard's attention to the fact that the essential part of his theory of formation of igneous batholites below rising arches, due to relief of pressure, is to be found in my theory of the formation of laccolites and batholites under such circumstances as given in 1921 in my "Earth evolution and its facial expression." The differences in density to which he appeals to support his isostatic argument are true for the least common of the sedimentary rocks, the calcareous ones.

Brief remarks were also made by Professor Reid.

NEW TYPE OF APPALACHIAN STRUCTURE

BY GEORGE W. STOSE

(*Abstract*)

Certain structures observed in the Paleozoic rocks of the Piedmont of southeastern Pennsylvania are neither typical Appalachian longitudinal folds, overturned and overthrust toward the northwest, nor normal drop-fault blocks typical of the Triassic. They consist of narrow belts of Cambrian quartzite projecting through younger Cambrian limestones.

It is shown that an adjacent belt of Triassic sandstone preserved in a graben is coincident in position with a syncline enclosing Ordovician shale, the negative element of post-Carboniferous time persisting into post-Triassic time. The narrow belts of Cambrian quartzites projecting through limestones are similarly explained as anticlinal horsts. Narrow anticlines formed under post-Carboniferous compressive stresses persisted as positive elements in the period of readjustment in post-Triassic time, and the limestones on their flanks have been faulted down, leaving anticlinal Cambrian quartzite horsts. Maps and sections illustrate the structures.

Presented in abstract from notes.

Discussion

Prof. W. H. Hobbs: I take very special satisfaction in this conclusion of Mr. Stose that post-Triassic block-faulting is an important element in the structure of an Appalachian area. In all, I spent some twenty seasons in intensive study of the southwestern New England section of the Appalachians. This work, begun under the direction of the late Professor Pumpelly, was started with the assumption that block-faulting had played no important part in producing the structures observed. It was only when the work had been carried southward, to include the Newark area of the Pomperaug Valley in Connecticut, that the importance of an elaborately complex system of block-faulting was recognized. The conclusion was drawn from the fact that all of

the scattered Newark areas had been observed to be affected by a similar system of faults, that the underlying and intervening pre-Cambrian rocks had been similarly affected. The work was carried out as a member of the staff of the United States Geological Survey, which refused officially to accept this conclusion as regards the pre-Cambrian complex, though admitting it for the Newark areas themselves.

Dr. EDGAR T. WHERRY: It is worth noting that there is evidence of considerable block-faulting of the type described by the author in the region lying to the northeast of that here described, namely, in the vicinity of Reading and Allentown, Pennsylvania, where I have done detailed mapping of the Triassic and adjacent Paleozoic rocks. However, the evidence in many cases seemed to indicate that when a block was bounded by two northeast-southwest trending faults, the southeastern fault would be of the normal type, with the downthrow on the southeastern side, while the northwestern boundary of the block would be a thrust fault, with the fault plane dipping to the southeast. In these cases the thrusts are evidently of pre-Triassic age, the normal faults of late and post-Triassic.

Prof. ANDREW C. LAWSON: While accepting the interpretation placed on these structures by Mr. Stose, I would question the propriety of classing them as Appalachian structures. The latter were developed at the close of the Paleozoic, under conditions of compressive stress. The structures described were developed at the close of the Triassic under conditions of tensile stress. These Triassic and post-Triassic structures should not be confused with the earlier and quite different Appalachian structures.

Author's reply to Prof. Andrew C. Lawson: The suggestion made by Professor Lawson is very pertinent and I gladly adopt it. The structure should be called a modified Appalachian structure, and the title might better read "A new type of structure in the Appalachians."

Miss ANNA I. JONAS: Extensive Triassic faulting of this type in the Piedmont is not limited to the area just discussed. The rocks of Chestnut, Hillam, and Pigeon hills and surrounding valley limestones are strongly faulted in a similar manner. West of Pigeon Hill, where the Triassic sandstones cut off the western end of the Lancaster-Hanover Valley, the faults can be traced directly from Triassic rocks through adjoining pre-Cambrian and Paleozoic rocks.

Dr. A. C. SPENCER: Faulting of the tilted block type, which H. B. Kummel regards as post-Newark, is exhibited by the geologic maps of the Franklin Furnace and Raritan quadrangles, folios 161 and 191 of the Geologic Atlas of the United States.

Brief remarks were also made by Dr. Charles P. Berkey.

THRUST FAULTS AND FAULTS IN SOUTHERN NEVADA

BY CHESTER R. LONGWELL[1]

(Abstract)

Recent work in the Spring Mountain Range has revealed thrust faults on a large scale, associated with overturned folds. These features are closely

[1] Introduced by H. E. Gregory.

connected with those reported by Hewett in the Goodsprings district, but the strike differs considerably in the two cases. Strong warping and important normal faulting have followed the thrusting. A number of steep faults at right angles to the thrusts and folds show differential lateral movement, and therefore resemble the transcurrent faults or flaws of the Alps. All of these structural features are represented also in the Muddy Mountains, 40 miles to the east. The youngest rocks known to be affected by the thrusting are Jurassic, but the disturbance may have occurred as late as the Tertiary.

Presented in abstract extemporaneously.

Brief remarks were made by Messrs. C. W. Washburn and F. P. Shepard.

GEOLOGY AND PHYSIOGRAPHY OF THE RED RIVER BOUNDARY DISPUTE

BY L. C. GLENN

(*Abstract*)

A number of extremely interesting, practical problems in geology and physiography were involved in the recent triangular litigation between Texas, Oklahoma, and the United States over title to lands along and in Red River. These will be outlined and their relationship to law as applied to rivers and boundaries and to the decision of the United States Supreme Court will be given.

Presented in abstract extemporaneously.

Brief comment was made by Prof. J. A. Udden, but there was no time for extended discussion.

ADDRESS OF THE RETIRING PRESIDENT OF THE PALEONTOLOGICAL SOCIETY

At this time, 12.30, arrangements had been made in the program for the address of the retiring President of the Paleontological Society, T. Wayland Vaughan, which was then given in joint session. Title:

CRITERIA AND STATUS OF CORRELATION AND CLASSIFICATION OF TERTIARY DEPOSITS

With the conclusion of this address, the morning session was adjourned for luncheon.

Session of Thursday Afternoon

The afternoon session was opened at 2 o'clock, in the auditorium, with President White in the chair.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

POST-GLACIAL CLAYS AT LITTLE FERRY, NEW JERSEY

BY CHESTER A. REEDS

(*Abstract*)

Post-Glacial laminated clays are exposed in large pits at seven places along the west bank of the Hackensack River in the vicinity of Little Ferry, New Jersey. These clays represent glacio-fluvial deposits laid down seasonally in fresh water, year after year, as the ice of the last glaciation (Wisconsin) was gradually retreating northward up the Hackensack Valley. From careful field and laboratory studies it has been determined that this deposition and retreat lasted about 2,500 years.

The initial layers of clay rest on the red glacial till which the glacier spread over the surface of the underlying red Triassic beds. The top of the clay is overlain by the "Yellow Drift," which varies in thickness from a few feet one-quarter mile distant from the Hackensack River, to 20 feet at some points along the banks of the river. The average thickness of this overlying deposit, which consists of beds of sand of various colors and a few well defined horizontal bands of clay, is about five feet.

The upper surface of the laminated clay, although apparently level at any given point, reveals on close inspection that the layers of clay have been beveled off by erosion subsequent to deposition and that the "Yellow Drift" rests unconformably on the laminated clays. The highest working-face noted in any one of the seven pits examined was 14 feet. In some of the pits only the lower layers are exposed and worked, in others those of an intermediate position, while in a third group some higher layers appear; but it is believed that these do not represent the last layers that were deposited, for the transition from the clay to the overlying "Yellow Drift" deposits is abrupt.

A close study of several series of actual sections taken in the field and correlated in the laboratory by matching layer for layer reveals a total thickness of 44½ feet of clay. One or more slidden zones appear in most every pit, but by taking samples of the corresponding varves in other pits, where the record is clear, the count has been established from the lowest to the highest layers except for about one foot at the base. The varves are prevailingly thicker near the bottom and nearest the river, but at various elevations in the section some surprisingly sudden changes in the thickness of the varves appear. While it is not possible to differentiate clearly the four seasons in each annual deposit, it is possible, with perseverance, to establish the chief periods of melting and freezing of each year—that is, the "summer" and "winter" layers of De Geer.

Read in abstract from manuscript.

The Chair announced that the papers by Doctor Reeds and by Professor Sayles, immediately to follow, were so closely related that the discussion would be held until after the reading of the next paper.

VARIABILITY OF SUMMER DEPOSITION IN GLACIAL VARVES

BY ROBERT W. SAYLES

(*Abstract*)

In July, 1923, an attempt was made to correlate the events of the summer components in thick varves in the glacial clays near Hanover, New Hampshire, at Mink Brook and at a locality two miles northwest of Mink Brook on the Vermont side of the river. Thick varves, averaging 4 inches, were measured carefully, and every variation in deposition was measured in each varve. It was found that these thick varves could not be matched in the two localities chosen so as to identify the years. By using the winter or clay components alone, however, and disregarding the summer components, it was found that the same years at the two localities could be easily matched. After matching the years, a comparative study of the summer components showed that they corresponded in a general way, but that in such thick deposits the currents concerned were probably too strong and variable to deposit similar thicknesses two miles apart.

It is concluded that if the various events of a summer season are to be recorded in the summer deposits, so as to be correlated several miles apart, such deposits must be made at a greater distance from the ice front than in the cases studied, or conditions of deposition must be different from those which prevailed during the retreat of the Wisconsin ice in the Connecticut Valley.

Presented in abstract extemporaneously.

Discussion

Dr. E. O. Hovey: The interesting and valuable paper by Doctor Reeds calls to mind the studies of Sir Douglas Mawson on some glacial clays near the Murray River, South Australia, the Cambrian tillites on the Sturt River, near Adelaide, and the Permo-Carboniferous deposits at Hallett's Cove, South Australia. Last August Sir Douglas told me about these studies and his arguing before the Australian Association for the Advancement of Science, in 1906, that their banding was due to seasonal deposition. Through his colleagues' disbelief in his arguments the Association refused to publish his paper, and therefore he lost the credit for the discovery in Australia. The indurated glacial clays or shales of Permo-Carboniferous age at Seaham, near West Maitland, New South Wales, are strikingly like the Little Ferry beds which Doctor Reeds has so well described and illustrated, but drag-folding is well developed in some of the strata.

Brief remarks were also made in discussion of Doctor Reeds' paper by Dr. William C. Alden, with reply by the author, as follows:

Author's reply to Dr. William C. Alden: In the Little Ferry district I had no difficulty in correlating varves as much as two miles apart, provided the same varve or series of varves was placed in apposition. The varves varied in thickness from place to place; nevertheless, the more prominent physical characters of each varve were duplicated in different places.

Discussion of Professor Sayles' Paper

Brief remarks were made in discussion of Professor Sayles' paper by Messrs. Chester A. Reeds, Harry Fielding Reid, and E. O. Hovey.

Dr. Chester A. Reeds: Professor Sayles' inability to correlate the more sandy portion or summer layer of each annual deposit at localities two miles apart may be due to the fact (1) that the limited number of varves exposed in each locality may not represent contemporaneous deposits; (2) that due to the coarseness of the varves and the close proximity of the ice at the time of deposition, particularly the more northerly of the two localities, the sandy or summer deposit, the variable member, may vary so in thickness that it is impossible to correlate them in localities as much as two miles apart. It should be borne in mind, however, that the correlation of varves is not based on the summer layers alone, but on the varve which includes both the summer and winter layers. It is significant that he could establish the contemporaneity of the deposits in these two localities by correlating the winter layers by the curve method of De Geer.

ARE SOME FOSSIL SOILS IN BERMUDA RECORDERS OF INTERGLACIAL EPISODES?

BY ROBERT W. SAYLES

(*Abstract*)

There are six or more fossil soils intercalated between strata of eolian limestone in Bermuda, and these, according to Verrill, occur mainly in the Walsingham formation. The soils range in thickness between 2 and 10 inches or more. According to Verrill's estimates, it would take not less than 10,000 years to form 1 inch of the soil by solution of the limestone, which contains not much more than 1 per cent of inorganic matter. This means that for the thicker soils not much less than 100,000 years would be required. As the main island stands today, the formation of eolian rock as observed could not have been possible. A greater extent of land would be necessary not only to supply the material, but for the wind to reduce and round the grains as they are found now in the greater part of these limestones.

During the Pleistocene period the conditions in Bermuda must have been different from those that obtain today. The writer has conceived the idea that some of these soils may mean interglacial conditions, when the climate was more like that of today, and when the water from the melted glacial ice had raised the sealevel 60 or more feet, and reduced Bermuda land to an area of something like its present size. The return of glaciation in the north, by lowering sealevel, would extend the area of Bermuda westward, laying bare much loose material in that direction. An increased force of the wind and greater cold would undoubtedly reduce and change the flora and make soil formation difficult, and pile up high dunes south and east as they are found today. Ten fathoms' reduction of sealevel would be sufficient to lay bare the present lagoon.

A recent subsidence of about 100 feet is called for by the evidence cited by

Verrill. Is this subsidence an actual subsidence of the islands or a raising of the ocean level by melted ice, or is it a combination of the two causes?

In speaking of the soil layers the writer has not forgotten the extremely thin soil layers found in the dunes at Provincetown, on Cape Cod, spoken of by Woodworth, where no such theory as that advanced above could hold.

In this abstract the writer is merely stating the problem. A short stay in Bermuda did not permit of much field work.

Presented in abstract extemporaneously.

OLDEST (NEBRASKAN?) DRIFT IN WESTERN ILLINOIS AND SOUTHEASTERN MISSOURI IN RELATION TO "LAFAYETTE GRAVEL" AND DRAINAGE DEVELOPMENT

BY FRANK LEVERETT

(*Abstract*)

The Illinoian drift of southwestern Illinois is underlaid by patches of much older, indurated and kaolinized, till that is referred tentatively to the Nebraskan glaciation from the Labrador center, and presumably a correlative or equivalent of the Jerseyan drift of the Atlantic coast. This glaciation appears to have extended across the Mississippi Valley into Missouri from the vicinity of Saint Louis southward, and deposited the boulders of granite, quartzite, diorite, etcetera, which are found for a few miles back from the river, granite boulders being found as far south as Cape Girardeau, Missouri. Still farther south near Commerce, Missouri, within the "Lafayette" area, quartzites are mixed in with the chert pebbles, suggesting a reworking of the "Lafayette" cherts by glacial drainage from the Nebraskan ice-sheet. The Mississippi, at the culmination of this glaciation, appears to have been diverted around the edge of the ice in southeastern Missouri, through a series of pools, across rock sills 200 feet or more above the level of the present stream, the place of diversion being near Labadie, Missouri, about 30 miles west of Saint Louis.

In the absence of the author, this paper was read in full from manuscript by Dr. William C. Alden.

Brief remarks were made by Messrs. George F. Kay and L. C. Graton, with replies by Doctor Alden.

EVIDENCES OF TWO GLACIAL STAGES IN THE SIERRA NEVADA

BY F. E. MATTHES

(*Abstract*)

That the Pleistocene glaciation of the Sierra Nevada was interrupted by at least one lengthy interval is not yet generally conceded as fully demonstrated, the evidences that have been adduced thus far being held by some geologists to be inconclusive. These evidences consist chiefly of older and younger moraines, differing in degree of preservation, and of certain sculptural effects produced by the ice. However, there are in the Sierra Nevada other and more convincing evidences that point to a lengthy interval of subaerial

erosion between the earlier and later ice advances, and that afford even a basis for a rough measure of the length of that interval. These evidences consist of isolated rock forms that project sharply above the surfaces overridden by the earlier ice, and that are clearly residuals left by long-continued, differential disintegration.

Among these residual forms are:

1. Pedestals composed of granite in place, several feet in height, that have been protected by capping boulders of the older drift.

2. Monoliths of monumental aspect, 5 to 20 feet in height, also composed of granite in place, that have survived by virtue of their massive structure.

3. Projecting dikes of aplite more resistant to weathering than the surrounding granite, that stand out as thin walls 7 to 10 feet in height.

The minimum depth of disintegration and stripping indicated by these residuals is 7 feet. This is a very large amount as compared with the slight reduction that has been suffered thus far by the same kind of rock since the passage of the later ice. The polish left by that ice notably remains preserved over large areas. It is evident, therefore, that a vastly greater length of time has elapsed since the recession of the earlier ice than has elapsed since the departure of the later ice. Furthermore, since there is ample indication that the later glaciers were relatively short-lived, it may properly be inferred that the greater part of the disintegration indicated by the pedestals, monuments and dikes was accomplished during the interval between the earlier and later ice advances. That interval, therefore, was presumably not less than several hundred thousand years in length—in any event—comparable in point of duration to some of the "interglacial stages" between the major extensions of the continental ice.

Read in abstract from manuscript.

Brief remarks were made by Messrs. George H. Chadwick and William C. Alden.

GENESEE GLACIAL LAKES

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

Restudy of the glacial history of the Genesee Valley of western New York, famous for its glacial lake succession, has considerably increased the number of lake levels and revealed significant oscillations of the ice-front. A chart will be exhibited and briefly discussed, especially with reference to correlations with other regions.

Presented in abstract extemporaneously.

Brief remarks were made by Prof. A. C. Coleman.

SUPPOSED GLACIAL FORMATIONS IN THE PRE-CAMBRIAN TERRANES OF THE ROCKY MOUNTAINS

BY ELIOT BLACKWELDER

(*Abstract*)

Boulder slates, which are probably ancient tillites, have now been found in the Medicine Bow Range of Wyoming, at two places in the Wasatch Mountains

of Utah, and more recently in low hills on the shore of Great Salt Lake. In some cases, the conglomerates are associated with finely laminated silt rocks and other formations typical of a glacial series. In some localities the beds are merely indurated, whereas in others they are considerably anamorphosed. Although striated surfaces are not available, the relations, structures and petrographic character of the rocks are such as to indicate their glacial origin.

In the Wasatch Range, the glacial formation lies unconformably beneath the Lower Cambrian series. In Wyoming, there is ample indirect evidence to show that the beds are of pre-Cambrian age. In the third case, the degree of anamorphism and other facts indicate that the formation is certainly ancient and presumably pre-Cambrian. A possible correlation of these putative tillites with those of Huronian age in eastern Canada will readily suggest itself.

In the absence of the author, this paper was read in abstract from manuscript by Prof. W. H. Twenhofel.

RECENT STUDIES OF THE PLEISTOCENE IN WESTERN IOWA

BY GEORGE F. KAY

(*Abstract*)

More than a decade ago the Pleistocene tills and associated materials of western Iowa were described in papers published by Udden, Calvin, Shimek, and others. In more recent years nothing has been written about these deposits, although they have been studied to some extent by several persons interested in glacial geology.

This paper is a result of several weeks of field study, chiefly in Pottawattamie, Harrison, and Monona counties and in adjoining counties farther east. The chief purpose of the investigation has been to determine whether or not a restudy of the tills, gravels, and related deposits of the area would permit, in the light of our most recent knowledge of the Pleistocene of southern, southwestern, and northwestern Iowa, a more satisfactory interpretation of the relationships and origins of these glacial materials than was possible when previous studies were made. Considerable additional field work will be necessary before final conclusions can be reached, but thus far the evidence warrants the following tentative statements:

1. The two oldest known tills, the Nebraskan till and the Kansan till, separated in many places by Nebraskan gumbotil of Aftonian age and in other places by peat, lignite, and soil zones of Aftonian age, have been traced as far west as the western parts of Crawford and Shelby counties, a distance of less than 25 miles from the Missouri River, the western boundary of Iowa. Moreover, in the southeastern part of the town of Council Bluffs, in Pottawattamie County, there is a distinctive zone of leached Nebraskan till separating unleached Nebraskan till below this zone from unleached, oxidized Kansan till above the zone. The evidence in hand seems to indicate clearly that both these old tills extend to the Missouri River and probably, also, beyond into the State of Nebraska. If it were not for the thick deposits of loess overlying the tills in this region, no doubt many additional good sections of these two tills could be seen.

2. In western Iowa it has not been possible to distinguish the Nebraskan till from the Kansan till by differences in color, texture, lithological composition, or degree of weathering. Only when it is possible to establish the relationship of an outcrop of till and associated gravel to gumbotil or other interglacial material whose age is known, can the definite age of the till and gravels be determined. When the till is overlain by Nebraskan gumbotil or can be shown to lie lower topographically than near-by remnants of the eroded Nebraskan gumbotil plain, then the till may be interpreted as being Nebraskan till. If, however, an outcrop of till is overlain by Kansan gumbotil, or if the till has the proper relation topographically to remnants of the eroded Kansan gumbotil plain, the till may be interpreted as being Kansan till.

3. The sands and gravels of western Iowa, which have been described by Shimek and Calvin as being Aftonian interglacial gravels separating the Nebraskan till from the Kansan till and related in origin neither to deposits made during the closing stages of the Nebraskan glacial epoch nor during the Kansan glacial epoch, are thought by the writer to represent not a distinctive stratigraphic horizon separating the Nebraskan till from the Kansan till. But instead they are interpreted as being lenses and irregularly shaped masses of gravels and sands within a single till; or, if in two tills, it is not possible to use the gravels and sands as evidence for differentiating these two tills. The gravels and sands are unleached and appear to be contemporaneous in age with the tills with which they are associated. This view is in accord with the author's interpretation, recently published, of the relationships fo till of the well-known gravels near Afton Junction and Thayer, in Union County.

4. Many mammalian fossils have been found in the sands and gravels associated with the tills of western Iowa. Calvin and Shimek believed that these remains were of animals which were living during the time of deposition of the gravels, which they interpreted as Aftonian and interglacial. But if the sands and gravels are lenses and irregularly shaped pockets related in age to the till with which they are associated, then a somewhat different interpretation of the age of the mammals becomes necessary. At the present time it is impossible to state whether the gravels in which the mammalian remains have been found are associated with Nebraskan till or with Kansan till, since, as stated previously, it has not been possible thus far to differentiate Nebraskan till from Kansan till except where the relationships of the till to gumbotil, the age of which is known, have been established. If the gravels in which the mammalian remains have been found should prove to be lenses and pockets in Nebraskan till, then the evidence would suggest that the animals are Nebraskan in age. It would be reasonable to assume that the animals were living in front of the advancing Nebraskan ice-sheet, out from which sands and gravels were being carried. Remains of mammals became imbedded in the sands and gravels, which themselves later were overridden by or became incorporated in the onward moving Nebraskan till. If, on the other hand, the sands and gravels containing the mammalian remains should prove to be lenses and pockets in Kansan till, then the suggested interpretation would be that the mammals were living on the Aftonian surface during the advance of the Kansan ice-sheet out from which sands and gravels were being carried. After remains of mammals became imbedded in these sands and gravels the

Kansan ice-sheet advanced and incorporated in Kansan till these masses of sands and gravels in which the remains are found. If these conclusions are justified, then this mammalian fauna may not be a strictly interglacial fauna of Aftonian age. It is important to note, however, that the fauna is certainly early Pleistocene—that is, it was either closely associated with the advance of the Nebraskan ice or with the advance of the Kansan ice-sheet, or it was associated with both as a result of having persisted on the adjacent plains from Nebraskan through Aftonian to Kansan time.

5. The name "Loveland formation" was given by Shimek to a deposit in western Iowa which is a "heavy, compact, reddish (especially on exposure to the air) or sometimes yellowish silt, which when dry is hard, with a tendency to break into blocks like a joint clay, and when wet becomes very tough and sticky and hence is sometimes called a gumbo." The type section of this formation is at Loveland, Harrison County. By early workers this formation was thought to be related to the widespread buff loess of the region, but Shimek believes that it is a fluvio-glacial deposit "formed during the melting of the Kansan ice." In many places it is calcareous and contains calcium carbonate concretions, many of which are from three to six inches in diameter; a few were seen with greatest diameter more than 12 inches. The Loveland does not show the laminations of water-laid clay, but in places sands and silts of distinct aqueous origin are interstratified with the Loveland clay; and in a few places volcanic ash is interbedded with the formation. Moreover, it has the vertical cleavage of loess and stands with similar vertical faces. Although in places fossil shells are present in the Loveland, they are extremely rare in comparison with the numbers of shells which are in the buff loess. The writer believes that the Loveland is not a fluvio-glacial deposit, but a loess distinctly older than the widespread buff loess which overlies the Loveland and which is thought to be chiefly of Peorian age; the Loveland is younger than the Kansan glacial epoch, since it lies upon the maturely eroded surfaces of Kansan till.

6. Northeast of the village of Little Sioux, in Harrison County, there are along the east slope of the Little Sioux River tills, gravels, and related materials which were described by Shimek as the county-line exposures. Here are fine, whitish "silts" which were thought by Shimek to be part of a section of sands and gravels which he interpreted as being Aftonian in age. Recently these "silts" were studied by Doctor Alden, who proved that they are volcanic ash. The writer is convinced that this volcanic ash is not of Aftonian age, but is of the same age as the Loveland loess, with which in some of the county-line exposures it is interstratified.

Presented in abstract extemporaneously.

Discussion

Dr. William C. Alden: I would like to call attention to the fact that the raising of a question, as to whether or not the fossiliferous gravels along the Missouri Valley north of Council Bluffs are truly interglacial, does not, in any way invalidate the standing of the Aftonian interglacial stage as such. The latter rests on a firm and independent basis. As to whether or not the animals,

whose remains were described by Calvin and Shimek, could have lived up close to the front of either the Kansan or the Nebraskan ice-sheet is perhaps a matter to be settled by the vertebrate paleontologists. If the gravels were deposited by streams flowing out from the advancing or retreating ice-fronts, it would appear that the animals must have been living in the valley either during the Aftonian interglacial stage or close to the ice just before or just after this stage. In any case Doctor Kay's interpretation makes little difference in the age of the fauna; it appears to be early Pleistocene, anyhow.

Last August I spent a week or ten days with Doctor Kay driving over the drift of western Iowa, and I would like to say that if there still remains in the mind of any one any doubt as to the verity of the Nebraskan and Kansan as distinct stages of glaciation much older than the Wisconsin and separated from each other by a long stage of deglaciation (Aftonian), he should get Doctor Kay to take him on such a trip as we took.

Brief remarks were also made by Messrs. J. A. Udden and A. C. Coleman, with reply by the author.

PHYSIOGRAPHIC DEVELOPMENT OF THE NORTHERN GREAT PLAINS

BY WILLIAM C. ALDEN

(*Abstract*)

This is a summary of results of several field seasons' study of Tertiary and Pleistocene gravel terraces and of associated glacial deposits of the plains of Montana, Big Horn Basin, Wyoming, and adjacent areas. In Oligocene and Miocene time the mountains and plains stood sufficiently high to give strong stream gradients and the waters flowed to Hudson Bay. Coalescent, piedmont, alluvial fans merged into extensive, gravelly plains. The few remnants of these are 1,000 to 2,000 feet above present streams. One is the deposit of coarse gravel and fossiliferous sands capping the flat top of Cypress Hills, Alberta and Saskatchewan. Probable correlatives are the deposits capping Tatman Mountain in Big Horn Basin, and high buttes in southeastern Montana and North Dakota; also erosion surfaces such as Beartooth sub-summit plateau northeast of Yellowstone Park, 4,000 to 6,000 feet above the plains; and similar surfaces (some of them lower) on Big Horn and other mountains. These postdate the Heart Mountain and Lewis overthrust faults.

Following this a succession of differential uplifts, alternating with long periods of repose, caused the streams to dissect deeply and erode broadly and to develop remarkably smooth, gravel-covered terraces, together with notable coalescent, piedmont, alluvial fans which may be grouped into three sets. These serve as datum planes, of which the first set comprises the fossiliferous gravel-covered Flaxville Plain of Collier and Thom and correlated terraces. This set was probably completed in Pliocene time after an uplift ranging from 2,000 feet or more in the mountains to 500 feet near the Dakota line. With the Flaxville Plain is correlated Hewett's "Rim terrace" in Big Horn Basin.

Other probable correlatives are such erosional features as the broad mountain valley of upper Clark Fork of the Yellowstone, in the bottom of which is cut an inner box canyon 1,000 to 1,300 feet in depth.

A second differential uplift of plains and mountains started the streams to eroding the Flaxville terraces and caused mountain glaciers to form and to extend out onto the piedmont terrace before it was greatly eroded. This uplift closed the Tertiary and the glaciers formed the oldest known Pleistocene deposits of the region. With the early mountain glacial drift are probably to be correlated the bouldery cap of Table Mountain near Lander, Wyoming, and similar caps of Bald, North, and Moncrief ridges at the east flank of Big Horn Mountains. I know of no observational ground for regarding features in this region, older than the pre-Wisconsin glacial drift on the Flaxville terraces in front of Glacier Park, as Pleistocene.

A long period of repose, following the second uplift, resulted in a second set of gravel-covered terraces now 150 to 300 feet or more above the bottom lands. Of two levels 100 to 150 feet apart, the lower is generally the best preserved terrace of the region. Correlatives are Hewett's "Sunshine terrace" of the Big Horn Basin and Blackwelder's "Circle terrace" on Wind River as early Pleistocene.

Waters of upper Missouri and Yellowstone rivers were probably diverted southward to the present course through the Dakotas by the Kansan ice-sheet, but it now seems doubtful if either the Nebraskan or the Kansan sheet invaded Montana.

A third differential uplift caused streams to cut 150 to 300 feet or more on the plains, and the third set of terraces was developed by valley broadening during the following period of repose. Correlatives are Hewett's "Greybull terrace" in Big Horn Basin and Blackwelder's "Lenore terrace" in Wind River Basin.

What may have been the first invasion of Montana by the Keewatin ice-sheet occurred after Missouri River had eroded the gorge through the Dakotas and after the development of the third set of terraces. This invasion diverted Missouri River in Montana. It may have been as late as the Iowan stage of glaciation. There were probably glaciers in the mountains at the same time, but the evidence is not clear.

At the early Wisconsin stage the Keewatin ice was somewhat less extensive, and at the later Wisconsin advance it extended into the northeast county of Montana but a few miles. Several mountain glaciers extended out onto the bordering plains distances ranging from 1 to 35 miles. Depths of recent stream-cutting range from 50 feet or less to 200 feet.

Presented in abstract from notes.

Brief remarks were made by Prof. A. C. Coleman.

POST-GLACIAL HISTORY OF THE CONNECTICUT RIVER NEAR MIDDLETOWN, CONNECTICUT

BY MALCOLM H. BISSELL[1]

(*Abstract*)

Near Middletown, Connecticut, the pre-glacial channel of the Connecticut River was blocked by drift during the retreat of the ice-sheet, diverting the

[1] Introduced by H. E. Gregory.

river past Middletown. Striking features of the drift in the abandoned channel are an esker about one-half mile long fringing Jobs Pond, and numerous large kettle-holes. Remnants of a terrace at an elevation of about 150 feet and containing many large boulders are also conspicuous.

The following facts appear to be particularly significant in relation to the post-glacial history of the river:

(1) The drift in the old channel shows no signs of later submergence or of reworking by flowing water.

(2) The top of the terrace is notably higher than the top of the esker in the channel (exact figures not available).

(3) The post-glacial course of the river makes a sharp swing at Middletown from the broad Triassic lowland into a narrow steep-sided valley in the crystallines of the eastern highland, joining the pre-glacial valley some three miles below. In spite of the difference in age of the two portions of the river, no difference in the form of its valley is discernible from the point where it enters the highland to its junction with the pre-glacial valley.

Two important conclusions are drawn from these facts:

(1) The present valley, from Middletown to the junction with the old channel, is not of post-glacial origin, but was carved by a large pre-glacial tributary of the Connecticut which entered from the west, following approximately the course of the present Mattabessett River. This tributary probably drained the Farmington Valley, cutting through the main trap ridge at Cook's Gap between Plainville and New Britain. The Connecticut was diverted across a short neck of lowland into the channel of this tributary when its own channel was blocked by drift.

(2) The old Jobs Pond channel of the Connecticut was never submerged after the retreat of the ice, nor occupied by a through-flowing stream. The terrace, therefore, is neither marine nor a true river terrace, but appears to have been built at a time when ice still occupied the channel.

Presented in abstract extemporaneously.

COAST EROSION

BY RAYMOND STANTON PATTON[1]

(*Abstract*)

Physiographic studies of the effect of wave and current action on the sand beaches of our Atlantic and Gulf coasts have not yet progressed to a point where the physiographer can furnish the engineer that detailed information regarding the evolution of the shore forms which the latter needs as a basis for his efforts to protect the beaches from erosion. While the general principles of that evolution are known, our present knowledge is qualitative rather than quantitative, and is not sufficiently specific to permit of its practical application to particular cases.

Demands for the protection of these beaches are already insistent in certain localities, and the future economic development which we are justified in anticipating must result in an increase in those demands.

[1] Introduced by W. Bowie.

Here, therefore, is an alluring field inviting the attention of the physiographer—a field in which the academic interest inherent in the problems to be solved is fully equaled by the immediate practical value which the solutions will have.

For example, the need for protection to the highly improved beaches of the New Jersey coast has become serious—in some cases even critical. Efforts by individuals or municipalities had frequently failed of adequate success. Therefore the State eventually assumed control of the problem. In addition to cooperating in the protection of various localities, it is making a comprehensive study of the fundamental problems involved in coast erosion and protection. For this purpose it has created an engineering advisory board of which the writer is a member.

The paper will discuss briefly that part of the work of this Board which refers to the physiographic rather than the engineering aspects of the problem.

The most pressing present need is for the collection of accurate data in sufficient quantity to produce authoritative studies. This Society can make a constructive contribution of material value by fostering such collection and study.

Read in abstract from manuscript.

RELATION OF FORMER DRAINAGE CHANNELS TO THE TOPOGRAPHY OF EASTERN PENNSYLVANIA AND MARYLAND

BY ELEANORA BLISS KNOPF

(*Abstract*)

From evidence furnished by a study of the drainage channels of master streams it is possible to show:

1. That there is within these channels a fairly continuous record of the successive fluvial erosion cycles.

2. That the stage of topographic development reached during many of these cycles was a submature to mature surface of erosion rather than a peneplain.

3. That the correlation of these remnants of former erosion surfaces is facilitated and strengthened by a study of the records of the erosion cycles that are preserved in the existent drainage channels.

Presented in abstract extemporaneously.

CUBIST SCHOOL IN TERRANAL CLASSIFICATION

BY CHARLES KEYES

(*Abstract*)

The "Cubist School" in modern painting has a distinctive style by which proper coloration effects are produced by means of different, bold, monochromatic blocks, or squarish patches, which blend at a distance into desired form and hue. By similar adaptation of cubist method terranal units give like graphical results and genetic cast to geological classification.

Possibilities of cubist scheme are of greatest practical import in a more or less advanced stage of stratigraphical progress. When once put into effect

its usefulness is preeminently constructive in new fields. Its unit of "blocking" is the provincial rock sequence, or terranal series. Such cubes are capable of union into larger patterns having chronologic span; or, in another direction, they are easily subdivided so as to meet all local requirements imposed by the various lithological, paleontological, or sedimental exigencies of almost any situation.

Evident superiority of cubist plan over all other methods of geological classification and correlation is indicated even by casual glance at a typical diagram. Some of the distinctive advantages are: (1) It is perfectly natural; (2) it is simplicity itself; (3) it is particularly precise; (4) it is essentially diagrammatic; (5) it is highly elastic; (6) it is severely regional in scope; (7) it is purely stratigraphic in character; (8) it is strictly genetic; (9) it is fundamentally indicative of diastrophic movements; (10) it reflects ancient physiographic expression; and (11) its standard formational unit is the maximum terranal unit. In fine, it is a real *multum in parvo* in stratigraphical practice.

In the absence of the author, the paper was read by title.

With the presentation of this paper the session closed at 5.35 o'clock.

Meetings of Thursday Evening

PRESIDENTIAL ADDRESS

At 7.30 o'clock the presidential address of the retiring President, David White, was delivered before the combined societies in the Auditorium of the Department of the Interior Building. The title of this address was "Gravity observations from the standpoint of local geology." This address is published in full in this number of the Bulletin.

The Auditorium was filled with the members and friends of the Geological Society and the affiliated societies, giving the largest attendance of any of the meetings.

At the close of the address the local committee arranged for moving pictures, showing explorations in the Canyon of the Colorado and other views of great interest, illustrating some of the striking features of American scenery and experiences of geological field parties.

ANNUAL SMOKER

At the conclusion of the presidential address, and while the moving pictures were being shown, the complimentary smoker was given by the Geological Society of Washington in the adjacent corridors. This was participated in by the Geological Society of America, the Paleontological Society, the Mineralogical Society of America, the Society of Economic Geologists, and friends. This was largely attended and gave opportunity for continuing the social life of the evening to a much later hour.

SESSION OF FRIDAY MORNING, DECEMBER 28, 1923

The morning session was called to order at 9.05 o'clock by President White in the Auditorium and the report of the Auditing Committee was called for. The following report was read by Sidney Paige, chairman of the committee:

REPORT OF AUDITING COMMITTEE

To the Council:

In examining the Treasurer's accounts we have checked the receipts and disbursements against their vouchers and find them correct. The bank balances, as shown by the Treasurer's accounts and the bank, correspond, allowance being made for outstanding checks. All interest on investments due to date has been collected. The securities in the Treasurer's hands in Baltimore will be checked later by a member of the committee and report thereon made to the Secretary of the Society.

SIDNEY PAIGE, *Chairman.*
ADOLPH KNOPF.
H. B. KUMMEL.

DECEMBER 27, 1923.

This report was received and accepted, conditioned on receipt of additional report covering the securities.

Sidney Paige, chairman of the committee, was delegated to make an examination of the securities of the Society and submit a written report to the Secretary to complete the committee's duties.

REPORT ON SECURITIES

Securities of the Geological Society of America in Safe Deposit of the Baltimore Trust Company

2 Texas and Pacific Railway Company first mortgage 5's, numbers 11915, 20892.
3 United States Steel Corporation second mortgage 5's, numbers 2964, 2974, 2975.
2 Fairmont and Clarksburg Traction Company first mortgage 5's, numbers 29, 30.
2 Consolidation Coal Company first and refunding mortgage 40-year 5's, numbers 11850, 11851.
2 Chicago Railways Company first mortgage 5's, numbers 20750, 20751.
2 Southern Bell Telephone and Telegraph Company first mortgage 5's, numbers M13217, M13218.
2 American Agricultural Chemical Company first mortgage 5's, numbers 5834, 6356.
1 Chicago Railways Company first mortgage 5's, number 45871.
1 Louisville and Nashville Railroad Company 10-year 7's, number 3941.
1 Braden Copper Mines Company 15-year 6's, number 4391.
1 Commonwealth Edison Company first mortgage gold bond, number 49652.

2 Anaconda Copper Mining Company first consolidated mortgage 6's, numbers M100571, M100572.
2 American Telephone and Telegraph Company 20-year sinking fund 5½, numbers M9957, M9958.
10 shares of the capital stock of the Iowa Apartment House Company, Washington, D. C.
40 shares of the capital stock of the Ontario Apartment House Company, Washington, D. C.

I have today inspected the above securities and find all in good order, with coupons attached.

SIDNEY PAIGE.

JANUARY 25, 1923.

The report of the Council, which had been laid on the table pending the approval of the Auditing Committee, was then formally approved.

At 9.10 o'clock Prof. Andrew C. Lawson, chairman of the Division of Geology and Geography of the National Research Council, appeared before the session and presented the following report on the problems and work of the Division:

WORK OF THE DIVISION OF GEOLOGY AND GEOGRAPHY OF THE NATIONAL RESEARCH COUNCIL

BY ANDREW C. LAWSON

It seems eminently fit and proper that in this great country of ours science should be represented by an institution having its home at the National Capital. In the National Research Council we have such an institution, originating in the stress of war from the recognition of the value of science to the well-being of the nation. The ideal of the National Research Council, as its name implies, is the fostering of scientific research, and to this its whole organization is devoted. The realization of this ideal requires the expenditure of large sums of money, and only a small portion of that money is as yet forthcoming. Whatever be the ideals and purposes of the institution, it is essential for its existence that it have an income adequate for the maintenance of its organization. Such an income the National Research Council has, but no more. The moneys needed for the prosecution of its scientific projects are difficult to find and many most worthy projects are languishing for lack of support. The Division of Geology and Geography, for example, has no funds whatsoever other than those necessary for the mere existence of the division. The work of the division is, therefore, inefficient, and will continue to be so until it has means to work with. It is the same kind of inefficiency as troubled the Israelites in Egypt when they tried to make bricks.

You will not be surprised, therefore, to learn that the real accomplishment of the division is small, and lies chiefly in that splendid domain where devotion to science more than offsets lack of money. Such work as the division is able to do without money is done through the agency of various committees,

and I will mention briefly what is being done by the more active of these committees:

The Committee on Abstracts and Bibliographies has continued its efforts to interest geologists in the matter of securing abstracts for the growing body of geological literature. As a result of this activity certain geological periodicals will demand from authors, as a condition of publication, a brief abstract to be published with the main paper. It is hoped that this practice may be extended, so that it may become a custom for all authors contributing geological papers to supply at the same time a brief abstract, and so contribute materially to a comprehensive system of abstracting all current geological literature.

The chairman of the committee, Prof. E. B. Mathews, has compiled a Catalogue of Published Bibliographies in Geology, and this has just come from the press as a Bulletin of the National Research Council of 228 pages. This catalogue embraces 3,699 titles and covers the period from 1896-1920. The work, therefore, is effectively a continuation of De Margerie's Catalogue des. Bibliographies Géologiques, published in 1896, and will be a valued reference book in every geological library.

The Division of Geology and Geography has for some years past recognized the desirability of securing for the science of geology an abstract journal covering the whole field of current geological literature, and this year, with the approval of the National Research Council, has engaged in a campaign to raise a foundation of $200,000 for the purpose of establishing and maintaining an Abstract Journal of Geology. The success of the project is by no means assured for this year, but the responses thus far received from the geologists of the United States indicate that the project has met with general and hearty approval. It is recognized that geologists can not themselves raise the large sum necessary, and an appeal is therefore being made to corporations concerned with the exploitation of the resources of the earth's crust, who are therefore to some extent indebted to geological science. It is hoped that these corporations will contribute the greater portion of the sum needed. The work of soliciting funds is now under way. It would be of material aid in the conduct of this campaign if the project might receive the endorsement of the Geological Society of America, and I hope that the Society will give me its approval.

The Committee on Studies in Petroleum Geology, under the chairmanship of Mr. K. C. Heald, has been active in promoting cooperation among the oil operators of the mid-continental oil field for the purpose of conducting research in scientific problems of common interest. This work is being continued as opportunity offers and a favorable outcome is hoped for it.

Following the admirable report on sedimentation compiled by the Committee on Sedimentation last year, under the chairmanship of Dr. T. Wayland Vaughan, it is proposed to prepare and publish, under the auspices of the National Research Council, a treatise on sedimentation. This work has been undertaken by Prof. W. H. Twenhofel, the present chairman of the committee. It will be a book of 800 to 1,000 pages, in 10 chapters, which will make a most timely contribution to geological science.

The Committee on Sound Sounding and Oceanographic Thermographs, under the chairmanship of Dr. T. Wayland Vaughan, has been active in the promo-

tion of oceanographic studies, chiefly through the agency of existing government bureaus.

The Committee on Tectonics, under the chairmanship of Prof. R. T. Chamberlin, last year undertook to review the progress of this branch of geology for the preceding year. The work was divided among the various members of the committee on a regional basis, and an interesting composite report was prepared, showing the activity in the study of tectonics in this country.

In the application of geology to industry the services of expert geologists are employed in making examinations and conducting explorations. These afford in many cases exceptional opportunities for securing observations of great value to science, but the corporations employing geologists very often forbid the publication of these observations or any discussion of them. In an effort to salvage some of this scientific information and to secure a more liberal attitude on the part of employers of geologists in the matter of releasing information, a committee has been established to make such representation to employers of geologists in general as will influence them to allow their experts greater freedom in making contributions to geology.

The doctrine of isostasy, though initiated by geologists, has been dependent for many years past upon geodetic methods for its substantiation. The doctrine is of the utmost importance to geology, but the areal range of its applicability is still in doubt. The basin ranges of the western part of the United States offer an opportunity not only for testing the validity of isostasy in general but for determining the limits of area for which the principle is operative. To bring about a series of field tests, based on the measurement of gravity in selected sections of the basin ranges, a committee has been established, under the chairmanship of Mr. William Bowie of the United States Coast and Geodetic Survey. It is hoped that the committee will effect the cooperation of the United States Coast and Geodetic Survey and the United States Geological Survey necessary for this work, and that the next field season will see the work begun. In furtherance of this project another committee was appointed to see what could be done to improve the methods of measuring gravity in the field. But this committee had scarcely been appointed when a distinguished physicist announced that he had devised a new and improved method of measuring gravity expeditiously in the field. It seems probable, therefore, that the testing of isostasy will have its work greatly facilitated by the new device.

A committee has been appointed to consider what can be done in the way of measuring geological time on the basis of atomic disintegration. The chairman of this committee is Prof. A. C. Lane, and with him are associated Messrs. H. V. Ellsworth, S. C. Lind, R. B. Moore, and R. C. Wells, all chemists interested in the problem of atomic disintegration. It is recognized that there are serious difficulties in attempting to measure geological time in this way, but it is hoped that the committee will find ways of overcoming these difficulties; and it is highly desirable that they should tell us to what extent the method is reliable.

Another committee on Diffusion in the Genesis of the Metalliferous Ores has been authorized, but its personnel has not yet been decided. This problem would require the work of a chemist for two or three years to secure results, and the project is in abeyance for lack of funds. There is, however, an excel-

lent prospect of having this important investigation undertaken in the immediate future.

At the conclusion President White called attention to the importance of the undertaking outlined by Professor Lawson, and further remarks were made by Professor Schuchert, who presented the following resolution:

Whereas, in the interval since last September, Chairman Andrew C. Lawson, of the Division of Geology and Geography of the National Research Council, has written to all the Fellows of this Society about the very desirable project of establishing an Abstract Journal for geologic science; and

Whereas, this matter has been under consideration by the Council of the Geological Society of America since the October meeting, with favorable recommendation: Now, therefore, be it

Resolved, That the Geological Society of America, assembled in annual meeting in Washington, December 28, 1923, most heartily expresses approval of the project, and approves also of the advice of the Council that the Geological Society undertake and be responsible for the gathering, editing, and publishing of such an Abstract Journal, provided the National Research Council raise and husband the necessary endowment.

The Fellows of the Geological Society also record it as their judgment that no greater aid can be given to stimulate and improve research work, not only of American geologists but to an equal degree the work of the geologists of the world. Not only can all geologists then keep in closer touch with what is being done in their fields of endeavor everywhere, but such broadening influence will surely suggest new fields of research. The Fellows of this Society, therefore, hope that it may be possible to find some way to carry this project forward, the fruition of which will surely stimulate investigation and make possible better and more abundant research in both the pure and applied branches of geologic science.

Professor Schuchert then moved the adoption of this resolution, which was seconded by Professor Hobbs. The motion was carried unanimously.

ANNOUNCEMENTS

Invitations were read from the United States Coast and Geodetic Survey, throwing open their governmental establishment to the inspection of members of the Society. Similar announcement was made by the local committee of other places of special scientific interest, assuring members that arrangements would be made to care for any who wished to visit these places.

Announcement also was made of the meeting of the Association of State Geologists.

At this point the reading of scientific papers was resumed.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

TERTIARY HISTORY OF THE NORTH ATLANTIC OCEAN

BY WENDELL P. WOODRING

(*Abstract*)

The middle Miocene (Helvetian) molluscan faunas of the West Indian and Mediterranean regions are remarkably similar in some features. It can easily be proved that many of the tropical genera occurring in both regions could not have migrated around the northern border of the present Atlantic basin, because they have never been found in temperate faunas of the same age farther north. It seems reasonable to believe that there were similar temperature zones south of the equator. As these mollusks are shallow-water dwellers, a series of shoal-water banks or islands across the Atlantic, within cruising range of larvæ, would afford the only means of migration. Most of the provincial genera in both regions may have no swimming larval stage, but this suggestion has not been verified.

The disappearance of the supposed shoal-water banks or islands may have been due to increased density, caused by the pouring out of basic lavas, thus paralleling the disappearance of the commonly accepted Tertiary landmass in the northern part of the north Atlantic. Isolated remnants of this Tertiary landmass are represented by the areas of Thulean Plateau basalts, with which plant-bearing beds are interbedded. These remnants extend from northern Ireland and western Scotland to Greenland and Spitzbergen.

Presented in abstract from notes.

Discussion

Prof. Charles Schuchert: It is very interesting to learn from Woodring the percentages of exotic and endemic Cenozoic, molluscan genera in the Antillean-Caribbean region on the one side of the Atlantic and those of the central Mediterranean area on the other. The close similarity of these shell faunas and of the echini and corals has long been known, and several authors have pointed out that their distribution must be due to either continuous or insular lands or to submerged banks. To make such a claim, however, for Miocene and Pliocene times is to ignore the fact that most of western Africa is bordered with Cretaceous and Eocene marine deposits, and, furthermore, that much of Brazil is also margined by Cretaceous (Gault) and later marine deposits.

I firmly believe in a greater Gondwana land across the Atlantic from Brazil to Africa, existing all through the Paleozoic and up to early Cretaceous time. With the immense extrusion of Thulean lavas in Africa and South America during the Jurassic and early Cretaceous, and the totally unlike mammal evolution of Africa and South America, we appear to have unmistakable evidence that Atlantic Gondwana sank into the depths of the ocean during late Mesozoic time.

The distribution of the marine invertebrates to either side of the tropical Atlantic must be explained by other means than by a continuous or discontinuous series of shoals.

Prof. ANDREW C. LAWSON: I do not see how the extension of basalt could depress the crust of the earth so as to convert a land area into an ocean basin. If the basalt came from a long distance—that is, beyond the limits of the area in question—it would, of course, impose a load upon the area; but, even then, the rock thus added to the area would have to be denser than that of the compensating flow in depth in order to effect any depression.

Mr. WILLIAM W. BOWIE: The gravity anomalies at stations located on the basaltic overflow in Oregon indicate that the portion of the earth's crust below is in isostatic equilibrium. There is a slight tendency for the gravity anomalies to be negative, but this fact may be accounted for by the presence of lighter material than normal near the stations. It seems probable that the outflowing material is not an extra load on the surface at the depth of compensation. Is it not probable that the outflow is merely the result of the expansion of the material of the earth's crust which results in an outpouring of the basaltic material through a fissure or fissures, rather than a general uplift of the surface material? Of course, there is an extra load on the outer surface, but this may be compensated for in the crust below by a decrease in density which just balances the material outpoured.

Prof. W. H. HOBBS: Great flows of basalts, quite apart from any speculations as to isostasy, are an *index* of great vertical movement associated with block-faulting. So much we may pretty confidently affirm.

Author's reply to Prof. C. Schuchert and Prof. A. C. Lawson: The late Tertiary transatlantic islands or shoals advocated have nothing to do with Gondwana Land or any supposed Mesozoic remnant of Gondwana Land joining South America and Africa. The similarity between the Miocene molluscs of the West Indies and the Mediterranean region is unmistakable and real. It is based on genera, not species, and the personal factor of evaluating similarities is almost wholly eliminated. Doctor Schuchert says there must be some other explanation for the similarity. But what other explanation is available? The only escape is to assume that all these tropical and subtropical genera will some day be discovered in the temperate, Miocene faunas of the north Atlantic, which is unreasonable, or that they will eventually be found in pre-Miocene deposits on both sides of the Atlantic, which is possible. I prefer to rely on what is known, rather than on what is not known.

If isostatic compensation were as perfect in Tertiary time as it is now claimed to be, it is difficult to make the inferred Tertiary history of the north Atlantic meet the test of isostasy. Overloading by the rise of basic magmas seems to be a possible explanation. The magmas may have come from adjoining earth blocks, and therefore would represent an addition of mass instead of a transfer in the same block.

GEOLOGICAL OBSERVATIONS ON A TRAVERSE THROUGH THE GRAND CANYON OF THE COLORADO

BY RAYMOND C. MOORE[1]

(Abstract)

On an expedition primarily concerned with the study of water power development, which between August 1 and October 15, 1923, made a voyage by

[1] By permission of the Director of the U. S. Geological Survey.

boat through the Grand Canyon of the Colorado from Lee's Ferry to the Grand Wash Cliffs, the writer had exceptional opportunity for investigation of the geology of the bottom parts of the canyon. Stratigraphic sections were measured at many points; lateral variation in the formations, especially of the Cambrian, was under observation almost continuously; the composition and structure of the pre-Cambrian rocks, including an undescribed area of Algonkian below the lower Granite Forge, was examined; deformation of the canyon formations by flexing and faulting, and evidences of volcanic activity affecting the lower canyon were somewhat carefully traced; and numerous features bearing on the topographic development and physiographic history of the canyon were noted.

Near Lee's Ferry excellent exposures of a significant unconformity between the Moenkopi and Kaibab formations are found in the canyon wall. The Kaibab limestone in the Marble Canyon section of the Grand Canyon is essentially similar to that in the well known Kaibab division, but the Coconino sandstone is much thinner. The Hermit shale, lithologically identical with the beds described by Noble at Bass Trail, has a thickness of more than 500 feet in Marble Canyon; the Supai consists mainly of massive, cliff-forming sandstones nearly 800 feet thick. The massive, Redwall limestone cliff exhibits most remarkable persistence, undergoing practically no change from the point where the formation appears in Marble Canyon to the Grand Wash Cliffs. Numerous remnants of the Devonian Temple Butte limestone are found in the lower part of Marble Canyon, but its maximum thickness is little more than 100 feet. The Cambrian Muav limestone is considerably thicker in Marble Canyon than in the eastern part of the Kaibab division of the Grand Canyon. The Bright Angel shale and Tapeats sandstone resemble closely corresponding formations described by Noble in the eastern Kaibab. In the western part of the Grand Canyon these formations are both increased in thickness, the Bright Angel being characterized by the appearance of prominent and very persistent dolomites, and the Tapeats by the addition of some hundreds of feet of weak sandstone above the cliff-forming, basal sandstone. Algonkian formations, similar to those in the Shinumo quadrangle described by Noble, appear at the lower end of the lower Granite Gorge and along Tapeats Creek. Their position, and a correspondence in general strike and dip, indicate that they compose a portion of the same great Algonkian wedge which is exposed along Shinumo Creek. Unlike the so-called Granite Gorges in the upper part of the Grand Canyon, which are dominantly cut in schists, the very long, inner gorge in pre-Cambrian rocks, which begins several miles above Diamond Creek and extends without break almost to the mouth of the canyon, is eroded mainly in granite.

The walls of the canyon in the Uinkaret and Shivwits divisions of the plateau province reveal much faulting, the lines of displacement trending in general north-south and the throw of all the main faults being on the west. The faults have evidently had little controlling influence on the course of the river, but have more or less importantly affected the development of secondary drainage. The lavas from vents on the Uinkaret Plateau have invaded the canyon at several points in geologically recent time, and there is evidence that, from the point of entrance into the canyon, lava flowed 75 miles or more downstream. The topography is intimately related to geology throughout

the Grand Canyon. Though the course of Colorado River with reference to present structure, the stripping of post-Paleozoic formations from the Grand Canyon plateaus, and other evidence point certainly to a rather complex, physiographic history, the erosion of the canyon has unquestionably been accomplished in a single cycle, one which is not yet far advanced.

Presented in abstract extemporaneously.

DISCUSSION

Prof. CHARLES SCHUCHERT: The wonderfully castellated land bounding the Grand Canyon of the Colorado is a paradise to stratigraphers, for here the fossiliferous marine strata may be followed in continuous outcrops for hundreds of miles. It must have been this stratigraphic and scenic paradise that lured our speaker into the dangers of this swift-running water, and we congratulate him and his associates upon getting through the great gorge unharmed and bringing to light the sedimentary knowledge of this wonderland of Paleozoic marine records.

ANTERIOR RANGE OF CONNECTICUT

BY WILBUR G. FOYE

(*Abstract*)

The agglomerates and pillow structure of the Connecticut Triassic have long been known, but it has not generally been understood that they are confined to the Anterior range. The paper will give a brief account of the chief localities where rocks showing these structures are exposed, and will discuss the origin of the pillow structure. It is believed that the basalt showing the pillow structure was, without doubt, extruded under subaerial conditions, and, therefore, the general rule that pillow structure is confined to subaqueous flows is not universally true.

Presented in abstract extemporaneously.

DISCUSSION

Prof. ANDREW C. LAWSON: I have seen pillow structure in basalts in various parts of the world, but none more perfectly developed than near San Francisco. The pillow structure there, as has long since been described, occurs in intrusive basalt. The evidence of intrusion is unequivocal. It has long since been shown that extrusion under the sea is not a necessary condition for the development of this structure.

Brief remarks were also made by Messrs. A. C. Coleman and L. C. Graton.

PHYSIOGRAPHY OF MONGOLIA

BY FREDERICK K. MORRIS[1]

(*Abstract*)

The hard-rock mountains bear a very perfect upland peneplane, which Doctor

[1] Introduced by Charles P. Berkey.

Berkey and I have called the Mongolian Peneplane. It was probably completed very early in Tertiary time, beveling the hard-rock and the locally disturbed Comanchean and Cretaceous basin-sediments. The basin-sediments themselves, ranging from Comanchean to Pliocene, are beveled by a second peneplane, extraordinarily perfect, called by us the Gobi Peneplane, which may correlate with the rock shelf and broad terraces in the hard-rock hills.

Below the Gobi Peneplane are eroded broad, shallow hollows with relatively flat floors, called the Pang Kiang stage. The origin of these hollows may be the work of water and wind erosion combined, and an effort is made to evaluate the work of each agent. The Khangai Mountains bear an old upland surface, which provisionally is called the Khangai Peneplane.

An attempt is made to correlate our observations in Mongolia with those of Bailey Willis and J. G. Andersson in China.

Glaciation in the Khangai Mountains is briefly described and illustrated.

Presented in abstract extemporaneously.

STRATIGRAPHY OF THE TSIN-LING-SHAN, CHINA

BY GEORGE D. LOUDERBACK AND R. R. MORSE

(*Abstract*)

On the basis of preliminary determinations of fossils, the following divisions are inferred:

Pre-Cambrian: (1) Gneisses probably corresponding to the Urgneiss and younger gneisses of von Richthofen and the Tai-Shan of Willis, previously recognized only in part in this region. (2) Schists, probably corresponding to von Richthofen's Wu T'ai, are shown to be widely distributed and definitely to represent alternations of sediments and volcanics. (3) A series of less metamorphosed sediments, possibly 12,000 feet thick, probably corresponding to the Sinian.

Paleozoic: Beginning with the Cambrian, the Paleozoic includes Ordovician and Silurian limestones and shales. Marine Devonian shows a much greater development than heretofore suspected. Middle Devonian is represented by 5,500 feet of sediments, and Upper Devonian, starting with the remarkable chert conglomerate 850 feet thick, totals about 3,100 feet. No definite Mississippian or Pennsylvanian horizons have been recognized, but the Permian is well developed, including marine limestone, coal beds, and a series of maroon shales and thin limestones, the whole totaling 6,000 to 7,000 feet.

The Mesozoic shows marine beds at the base, possibly Triassic, but is chiefly represented by the great series of red beds underlain by coal measures carrying supposedly Jurassic plants. These beds were in part deposited well over the area now occupied by the mountains.

The chief periods of diastrophic disturbance were pre-Cambrian, post-Permian, and post-Jurassic (or post-Mesozoic). Granitic intrusions occurred in the early pre-Cambrian and during the post-Permian folding. The latest movements were those of block faulting in late Tertiary or (and) post-Tertiary time.

Presented in abstract extemporaneously.

DISCUSSION

Prof. A. C. LANE: Professor Grabau has written to me, outlining the plan of referring the Sinian to the Paleozoic, though "pre-Cambrian," and comparing it to the Keweenawan, with which it has obvious points of resemblance. It is to be noted that neither is known to be pre-Olenellus, and is structurally more affiliated with the overlying belts.

Prof. ANDREW C. LAWSON: It is interesting to observe that the marked depression on the flank of the range, deeply filled by sedimentary deposits derived from the range, is in accordance with what might be expected from the operation of isostatic compensation. As the range was denuded, the block would rise and the adjacent blocks would sink by reason of transfer of mass in depth to maintain balance.

Mr. F. K. MORRIS: In Mongolia, also, a great series of greenstones and chloritic schists was observed by geologists of the Third Asiatic Expedition. These rocks were correlated provisionally with the Wu T'ai Shan series, the older Proterozoic of China; and it is gratifying to find that similar conclusions have been reached independently for the chlorite and greenstone rocks of the T'sing Ling Shan. In answer to Professor Lawson's question, it may be said that calcareous algæ, so abundant as to form reefs, are found in the Sinian limestones of Upper Proterozoic or pre-Cambrian Paleozoic age in northern China.

Prof. CHARLES SCHUCHERT: It appears to me to be all wrong to speak, as does Grabau, of a "pre-Cambrian formation" as of the Paleozoic. This is an unwarranted extension of the Paleozoic. If the whole of the Algonkian, Beltian, or Keweenawan series is to be included in the Paleozoic because in many places they are not angularly unconformable beneath the fossiliferous Paleozoic, we lose all value of the idea that, beginning with the Cambrian, all subsequent strata are correlated and chronologically determined on the basis of their abundantly entombed fossils.

I hold that the best results in stratigraphy will be obtained if all unfossiliferous formations beneath the Paleozoic are called Proterozoic or Archeozoic until they are shown to be younger in age. If any such formations can be laterally traced to pass into fossiliferous Paleozoic strata, then, of course, they should be added to the Paleozoic era.

Brief remarks were also made by Dr. Charles P. Berkey.

HURONIAN COMPLEX NEAR KILLARNEY, ONTARIO

BY TERENCE THOMAS QUIRKE

(*Abstract*)

Huronian sediments, unmistakable in identity, are cut off by intrusive, igneous rocks which were called Laurentian by Logan, Barlow, and Bell. The age of this granite has been established by Collins as Keweenawan. The Huronian sediments are faulted against granite gneisses as well as intruded by granite, and the area of gneisses stretching eastward from the Huronian sediments is largely of sedimentary origin, retaining here and there masses of metamorphosed sediments which can be recognized and mapped as

members of the Bruce and Cobalt series. These recognizable sediments can be traced along their strike, through gradations, into feldspathic gneisses of igneous aspect. Quartzites can be traced into granitic gneisses; greywacke into garnetiferous and syenitic gneisses; diabase and limestone into amphibolite; conglomerate into pegmatite. Many sediments have suffered replacement by the introduction of feldspar, and by the great concentration of feldspar they have been altered into a rock which is of igneous composition, although it has never been melted. These transformations have gone on under such conditions that the sediments have lost neither their solidity nor their structural behavior as stratigraphic members under contemporaneous deformation. True granite is almost confined to a strip which borders the great fault contact.

The stratiform gneisses continue the type of structure which is characteristic of the Huronian formations to the south of Espanola and Lake Panache, where they are not intruded by granite.

The gneissic complex is interpreted as a deep-seated equivalent of the strip of intensely folded Huronian rocks which border the north shore of Lake Huron; however, it has been saturated by igneous minerals and partly replaced by igneous intrusions at considerable depth; it has been faulted upwards at about the time of igneous intrusion, and later denuded by erosion. Liquefaction seems to have followed the main fault plane; elsewhere the Huronian sediments seem to have retained their solid character throughout their alteration into gneisses.

These Huronian gneisses and Keweenawan granites have been named Laurentian, and have been mapped as the continuation of the Grenville gneisses and Laurentian granites of the famous Haliburton area. This requires some revision of the opinions concerning the relative ages of the series called Grenville, Huronian, and of the Killarney and pre-Huronian granites. The whole gneissic complex is likely to throw light upon the alteration of sedimentary rocks into those of igneous type.

Presented in full extemporaneously.

DISCUSSION

Prof. ANDREW C. LAWSON: It is a great satisfaction to listen to this important contribution to our knowledge of the pre-Cambrian. As a pioneer in this field, I have watched with interest the growing appreciation of the necessity of intensive field studies in the problems of the Archean. For several decades reconnaissance surveys were considered adequate for the elucidation of the most complex problems in the whole range of geology. Today these problems are being attacked in limited areas with the most careful field methods, and notable progress is being made by Canadian geologists in this most interesting field.

PRE-CAMBRIAN ROCKS OF THE WESTERN PIEDMONT OF MARYLAND

BY ANNA I. JONAS

(*Abstract*)

Detailed study of the crystalline schists of the western Piedmont of Maryland has resulted in a separation of the formations in that area, determina-

tion of their age and relations to each other and to previously studied pre-Cambrian rocks of the eastern Piedmont of Maryland.

The oldest rock of the western Piedmont of Maryland is the Cockeysville marble. It is interbedded with metamorphosed volcanic rocks, which are for the most part green, epidotic amphibolites derived from amygdaloidal basalts. The meta-basalts are interbedded with chlorite-sericite schists which may represent altered tuffs or rhyolite flows.

The Cockeysville marble and interbedded volcanic rocks are overlain by the albite schist facies of the Wissahickon formation, which covers a wide area in the western Piedmont of Maryland. The marble and associated volcanics are exposed in an anticlinal axis which crosses the area in a southwesterly direction through Dug Hill Ridge, Westminster, New Windsor, and Union Bridge, Maryland.

The volcanic rocks are overlain unconformably by basal Cambrian sediments and therefore are pre-Cambrian in age. They form part of a volcanic outpouring which took place in the area of the western Piedmont of Maryland and Pennsylvania during the deposition of the Glenarm series, probably in Proterozoic times.

Presented in abstract from notes.

DISCUSSION

Dr. CHARLES P. BERKEY: This is a very welcome contribution to a very difficult, regional problem. It is based on the discovery of structural relations whose significance is apparently unmistakable. The general problem of correlation to which it applies is one of surprising obscurity, on which there has been much difference of opinion among good geologists. The major conclusions with regard to age relations of the principal units agree closely with those reached in my work in southeastern New York, where, however, the argument had to be made on quite other grounds. In that field there is complete failure of conclusive structural relations such as Miss Jonas has found in Maryland.

Mr. ARTHUR KEITH: I wish to join Professor Berkey in expressing my appreciation of this work. I am reminded by it of the old controversy centered upon the "blue" and the "white" limestone of the New Jersey Highlands, one of which was finally proved to be pre-Cambrian and the other Ordovician. In this Maryland instance of juxtaposition of pre-Cambrian and Ordovician limestones, geologists and their science are to be congratulated that detailed and apparently determinative work has preceded the formation of conclusions and perhaps a controversy.

BELT SERIES IN MONTANA

BY ROY A. WILSON,[1] J. S. LAMBERT,[1] AND C. H. CLAPP

(*Abstract*)

The completing of the reconnaissance geological survey of western Montana has made possible a fairly definite correlation of the different groups which

[1] Introduced by C. H. Clapp.

make up the Belt series, and to reconcile the different correlations that have been previously proposed. The calcareous members of the Forty-ninth Parallel section—the Altyn and Siyeh—are respectively correlated, on the basis of lithologic similarity and of stratigraphic continuity and position, with the Newland and Helena (Spokane group) of what may be termed the Forty-seventh Parallel section. The predominantly terrestrial sediments of the upper belt of the Forty-ninth Parallel section are correlated with the "red rocks" of the Spokane group in southwestern Montana. The thinning and change of lithology to the east and west of the 115-116th meridian section is also brought out.

Presented in full extemporaneously by Professor Wilson.

Discussion

Prof. A. C. Lane: Mr. R. M. Bennett, of the American Institute of Mining and Metallurgical Engineers, has been doing some work, as yet unpublished, on the Montana Belt formations. Have you found in your section the Purcell amygdaloids?

Mr. Edward Sampson: I have given some study to the correlation of the Belt series in the region covered by Messrs. Wilson, Lambert, and Clapp, in connection with work in the Pend Oreille District of Idaho.

I wish to protest against the application of Belt Mountain formation names to Rocky Mountain sections, as the present state of our knowledge does not make any correlation between these two regions sufficiently certain. In particular I would protest against calling the Wallace formation Newland and the Camp Creek series Spokane.

I agree thoroughly with the principle of progressive and systematic variation of sediments from east to west, as stated by Daly and emphasized by Mr. Wilson, and I also agree with the statement of Mr. Wilson as to the grouping of sediments, especially as to the middle siliceous group, which in the eastern part of the territory is underlain and overlain by calcareous rocks. I would, however, include the Burke, Revett, and Saint Regis formations in this central, siliceous group, making the Wallace and Striped Peak formations equivalent to the type Siyeh, and the Prichard formation (and Alderidge) equivalent to the Altyn formation.

Mr. Wilson correlates the Newland with the Altyn, and in this I agree. However, if Altyn (and consequently Newland) be correlated with the Wallace, the Striped Peak, which overlies the Wallace, becomes equivalent to the Hefty and Macdonald, which overlie the Altyn in the Galton Range (and Appekunny, which overlies the Altyn in the Clark Range); but Schofield and Daly have given strong evidence that the Striped Peak is not the equivalent of these formations, but is equivalent to upper Siyeh.

Therefore, I regard the Wallace (and Blackfoot) equivalent to the Helena and Empire, and the Saint Regis, Revett, and Burke (Ravalli group) equivalent to the Spokane and Grayson of the Belt Mountains.

Brief remarks were also made by Prof. Andrew C. Lawson, with reply by Professor Wilson.

RELATIONS OF THE BROWNS PARK FORMATION AND THE BISHOP CONGLOMERATE AND THEIR ROLE IN THE ORIGIN OF GREEN AND YAMPA RIVERS

BY JULIAN D. SEARS [1]

(*Abstract*)

The paper is an attempt to show that the Bishop conglomerate of northwestern Colorado and southern Wyoming is not younger than the Browns Park formation, as generally supposed, but is its basal member; that their discordance in elevation and the synclinal attitude of the Browns Park (lying on the crest of the Uinta Mountain-Axial Basin anticline) were caused by collapse of the eastern part of the Uinta Mountain arch; and that the courses of Green and Yampa rivers could not be antecedent, but are due to superposition from the Browns Park formation.

Presented in full extemporaneously.

Brief remarks were made by Mr. David White.

STRUCTURE OF THE BEARPAW MOUNTAINS, MONTANA

BY FRANK REEVES [2]

(*Abstract*)

The Bearpaw Mountains, one of several isolated mountain masses in the Great Plains east of the main Rocky Mountain system, are approximately circular in outline and about 35 miles in diameter and consist of volcanic flows and intrusive rocks which rest on and cut a floor of Cretaceous sediments. Their unusual structural history presents the following sequence: (1) An early Tertiary doming by a deep-seated intrusion, (2) a period of extrusive activity resulting in the accumulation of several thousand feet of volcanic material, and (3) intrusions into the volcanic rocks and the immediately underlying sedimentary beds, which were accompanied or followed by a subsidence of the mountain area and the development of a belt 30 miles wide of concentric, narrow folds and thrust-faults in the flat-lying, Cretaceous sediments surrounding the mountains.

The two especially noteworthy features—the subsided mountain block and the circumferential belt of folds and faults—are strikingly developed and present some unusual types of structure. The subsidence of the mountain area was apparently caused by the overloading of the crust by igneous material. The resultant flattening of the mountain arch may have produced the buckling in the strata surrounding the mountains.

Read in full from manuscript.

[1] Introduced by M. R. Campbell and W. C. Mendenhall.

[2] Introduced by D. F. Hewett and W. C. Mendenhall.

KEYSTONE FAULTS

BY W. O. CROSBY AND IRVING B. CROSBY[1]

(*Abstract*)

Master joints converging downward and bounding V-shaped blocks of rock of more or less acute angle and varying magnitude, may be momentarily opened by tensile stress during the passage of earthquake tremors. When this happens, the unsupported or imperfectly supported V or Keystone promptly drops as into a vise, and is more or less extensively broken and crushed, at least in the upper part, by the powerful, compressive stress of the succeeding phase of the earth vibration. This dual action or alternation of tension and compression may be repeated several or many times during the passage of an earthquake, the depressed block sinking deeper with each pulsation.

The result, structurally considered, is a linear block or trough fault. In other words, a keystone fault may be defined as a narrow graben. In recognized examples the opposing walls of the vise are usually approximately vertical; and the chasm may terminate horizontally as well as vertically by the gradual convergence of the walls, or abruptly, against a transverse joint, thus making more complete the analogy to the block faults or grabens.

The type example of the keystone faults is Purgatory Chasm, in the town of Sutton, Massachusetts. This was briefly described and discussed by the elder Hitchcock and later by the senior writer of this paper, but merits more attention than it has yet received. In recent years many examples, in part of pre-glacial but mainly of post-glacial origin, have been found widely scattered over New England and the glaciated zone generally. It is believed that we find here the really significant and impressive instances of post-glacial faulting. The dynamic and structural relations of the phenomena are discussed, and the general conclusion reached that we find here a new, or at least a neglected, geological principle.

Read by title in the absence of the authors.

At 1 o'clock the session was discontinued for luncheon.

Sessions of Friday Afternoon

Two joint sessions were held on Friday afternoon, one a joint session with the Paleontological Society in the Auditorium, and the other a joint session with the Mineralogical Society of America in the Conference Room of the Director of the United States Geological Survey.

[1] Introduced by W. O. Crosby.

JOINT SESSION OF THE GEOLOGICAL SOCIETY OF AMERICA AND THE PALEONTOLOGICAL SOCIETY

Dr. T. Wayland Vaughan, President of the Paleontological Society, presided at this session.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

GEOLOGIC SECTION ACROSS THE COAST RANGES OF CALIFORNIA

BY GEORGE D. LOUDERBACK

(*Abstract*)

The graphic section presented shows the following features:

The characteristic western axis of oldest rocks, flanked by Jurassic and later formations, with gaps representing diastrophic disturbances during the Mesozoic and Tertiary periods. A synclinorium involving rocks from Jurassic to lower Pliocene, within which the formations all show sharp faulting, including overturning and thrusting, present folds, having received their dominant forms chiefly from the post-lower Pliocene folding. Western limit of the synclinorium passes into an anticline exposing Jurassic strata, a typical feature of the ranges lying west of the valley of California. The post-Jurassic formations dip eastwardly away from this axis and disappear under the valley with low dips. Post-Pliocene faulting and differential movement of crustal blocks continued to the present, determine certain characteristic features of the profile.

Presented in abstract extemporaneously.

DISCUSSION

Mr. ROBIN WILLIS: In field-work in the region 100 miles to the south of San Francisco Bay the same divisions of the Coast Ranges suggested by Doctor Louderback were found. There seems to be a definite relation between the underlying, older formation and the character of the Tertiary and the type of deformation. West of the San Andreas fault, in the block underlain by the basement complex or Santa Lucia, the Tertiary formations are thin; the region has been stable as to elevation, and comparatively resistant to deformation. East of the fault, in the region underlain by the Franciscan, the blocks have been very active, alternating great uplifts shown by the unconformities with subsidences which have permitted the accumulation of a Tertiary section from 10,000 to 30,000 feet thick. These blocks have been structurally weak, and even the middle Pliocene formations show intense deformation in some localities.

FRANKLIN MOUNTAINS[1]

BY M. Y. WILLIAMS

(*Abstract*)

The Franklin Mountains are the extreme northeastern extension of the Rocky Mountain system. They are situated east of Mackenzie River, and extend from latitude 62° 45′, northward beyond Great Bear River, probably to latitude 65° 30′.

During two summers' work in the mountains the writer has made the following contributions to geological knowledge:

The structure is that typical of the Rocky Mountain system—that is, fault blocks, with downthrow to east and gentle slopes to west, overthrusting and close folding being minor features.

Rocks of middle Silurian and middle Devonian age have been previously recognized in these mountains, but the following section below the Devonian is the writer's.

Outline of Formations

				Thickness
Recent			River silts and soils.	
Pleistocene			Till outwash sands and gravels	200 feet ±
			Erosion surface.	
Eocene			Silts and semiconsolidated sands and gravels containing lignite beds	200 feet
			Contact not seen.	
Cretaceous			Shales and sandstone containing marine molluscs.	100 feet +
			Contact not seen.	
Devonian	Upper	Simpson Shale	Dark gray shale containing thin limestone beds.	1,000 feet ±
			Conformable contact.	
	Middle		Gray limestones, containing fairly rich and varied fauna	2,000 feet ±
			Disconformity	
	Upper	Mount Charles formation	Brecciated, massive dolomite, containing interbedded gypsum and chert. No fossils	1,600 feet

[1] By permission of the Director of the Geological Survey of Canada.

Outline of Formations (Continued)

					Thickness
				Conformable contact.	
Silurian	Middle	Mount Kindle formation		Waterlime and gray magnesian limestone, with Niagara coral fauna....	560 feet
				Disconformable contact.	
	Lower	Franklin Mountain formation		Buff limestone, buff and red shales. *Rhipidomella circulus* and *R. hybrida* near top.....	500 feet ±
Cambrian	Middle	Saline River formation		Buff and green shale, red shale, salt and gypsum. Fossils in shale are *Lingulella* sp., *Micrometra* sp. and *Obolus mcconnelli*	500 feet ±
				Covered interval of several hundreds of fee.	
		Mount Cap formation		Green shales, rusty shales and sandstones. Fossils include *Lingulella* sp., *Bothyuriscus* 2 sp., and *Ptychoparia* sp.....	200 feet ±
				Conformable contact.	
	Lower	Mount Clark formation		Pink quartzite, ferruginous grit and conglomerate. *Salterella* and *Olenellus canadensis* near top....	600 feet +
				Disconformity.	
Pre-Cambrian	Beltian?	Lone Land formation		Dark shales, gray and drab shales.....	375 feet +

The upper Devonian, Cretaceous, and Eocene formations occur in the vicinity of the Franklins, but not in the mountains themselves.

The Beltian rocks are identified on lithological grounds and from their position below the lower Cambrian, and the writer is indebted to Dr. S. J. Schofield for the recognition of their age. The fossils from the Cambrian formations have been identified by Dr. C. D. Walcott.

The presence of Beltian, lower and middle Cambrian and lower and upper Silurian formations in this region extends greatly the known extent of the seas of these periods.

In the absence of the author, this paper was read by Professor Schuchert.

DISCUSSION

Mr. ALFRED H. BROOKS: Professor Williams' paper describes the Franklin Mountains as a part of the Pacific arc and correlates their trend-line with those of the Endicott Mountains of northern Alaska. I ask what the evidence is of the continuity of the Franklin Mountains folding with that of the Endicott Mountains? These last appear to mark a period of deformation of Jurassic age. The axes of their resulting folds are marked by a shallow, northerly-facing arc roughly paralleling the Polar Sea. It appears to be extended along the margin of the Arctic Ocean in northeastern Siberia and is probably coextensive with Werojanski Mountain arc of the Lena River basin. Its eastern extension will probably be found in the folded rocks of the Canadian Arctic Archipelago. If this system of folding is, as I believe, traceable for at least fifteen hundred miles parallel to the Arctic Ocean, it can probably not be assigned to Pacific folding.

Brief remarks were also made by Mr. C. W. Washburne.

STRATIGRAPHY OF THE CRETACEOUS-EOCENE TRANSITION BEDS IN EASTERN MONTANA AND THE DAKOTAS

BY W. T. THOM, JR.,[1] AND C. E. DOBBIN[1]

(*Abstract*)

Recent field-work indicates that in the Plains basins of eastern Montana and western Dakota sedimentation continued without important interruption from marine Cretaceous into Wasatch Eocene. The Lance and Fort Union formations are separable into several lithologic units of large areal extent and of alternating somber and yellow aspect. In Montana, the Fox Hills sandstone is overlain in ascending order by the Hell Creek and Tullock members of the Lance; by the Lebo and Tongue River members of the Fort Union; by the Sentinel Butte shale (Fort Union?); and by the Wasatch Ulm coal group. In Dakota, the Hell Creek member (Lance) is overlain by the interfingering Ludlow and Cannonball marine members of the Lance, by the Tongue River member of the Fort Union, and by the Sentinel Butte shale, the upper part of the Ludlow and Cannonball members being equivalent to the Lebo shale member of the Fort Union of areas farther west.

The faunal, floral, and lithologic evidence all indicate the local continuity of sedimentation from Fox Hills into Wasatch. The Cretaceous-Eocene contact is provisionally placed at the top of the Tongue River member of the Fort Union, although the base of the member or the top of the Sentinel Butte shale may eventually be found to be more convenient planes of separation after further work in related areas.

First part presented extemporaneously by W. T. Thom, Jr.; the last part read from manuscript by C. E. Dobbin.

Brief remarks were made by Dr. Whitman Cross.

[1] Introduced by W. C. Mendenhall and M. R. Campbell.

CHAGRIN FORMATION OF OHIO

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

The revision of the Upper Devonian begun in western New York has been carried through to the Cuyahoga Valley of Ohio by exhaustive use of the published reports, especially Prosser's highly detailed account. A subdivision and correlation of the Ohio Chagrin formation, based on I. C. White's classification in Erie County, Pennsylvania, will be presented, together with the evidence of an overlap unconformity of the Cleveland-Bedford-Berea series on these upper Devonian (Bradfordian) strata, as shown in the chart previously published in the Bulletin of the Geological Society of America, 1923.

Presented in abstract extemporaneously.

EROSION BY SOLUTION AND FILL

BY WILLIS T. LEE

(*Abstract*)

Erosion of an unusual type is going on in southeastern New Mexico. Although there are no permanent streams and few dry water-courses east of Pecos River, in Eddy County, a broad valley has been formed. The red beds of Permian and Triassic age contain thick beds of limestone, gypsum, and rock-salt which become cavernous by solution. Storm waters find their way through sink holes into the caverns and by subterranean passages to the river. Some of the caverns in the limestone are very large. One near Carlsbad is said to have the largest chambers ever discovered in a limestone cave. Those in the gypsum and salt beds are smaller. Into these caverns dust is blown by the wind, silt is washed by the floods, and blocks fall by collapse of roof. The rock waste, replacing material removed by solution, lowers the surface and has in large measure formed the broad valley of Pecos River.

Presented in abstract extemporaneously.

DISCUSSION

Dr. T. WAYLAND VAUGHAN asked Doctor Lee about the ornamentation of the walls, roof, and floor of the cavern.

Dr. I. C. WHITE: Professor Lesley long ago called attention to the solution of limestones by underground waters as one of the principal agents of erosion, all our great limestone valleys, like the Greenbrier and Shenandoah in West Virginia, being due to this agency. The only lake we have in West Virginia, namely, one near Peterstown, in Monroe County, being due to the tamping of a large sink hole by cattle in tramping about over its bottom, and thus sealing up the underground outlet of its former drainage.

Brief remarks were also made by Mr. M. M. Bramlette.

NEW FORMATION IN THE TAMPICO EMBAYMENT REGION

BY J. A. CUSHMAN AND EARL A. TRAGER[1]

(*Abstract*)

An examination of the foraminifera from outcrops and well cuttings within the Tampico embayment region west of Panuco showed a distinct formation above the Papagallos. This was later found to be at least 1,000 feet thick in parts of the area. It occurs as outcrops about Velasco, on the Mexican National Railway, and is named the Velasco formation from this locality. It is closely related to the Taylor marl of Texas.

Presented in full extemporaneously by the senior author.

DISCUSSION

Dr. T. WAYLAND VAUGHAN asked if the Globigernia-bearing clays at Panuco belong to the Velasco formation.

Prof. JOSEPH T. SINGEWALD, JR., asked whether the Velasco formation is not upper part of shale series called Papagallos and beneath the overlying series of calcareous sandstones and shales called Chicoutepec and not, as Doctor Galloway suggested, that the Velasco formation is in part, at least, equivalent to the Chicoutepec.

Brief remarks were also made by Dr. J. J. Galloway, with reply by the author, as follows:

The Velasco formation has a distinctive fauna from that of the underlying Papagallos and very different from certain more or less barren strata referred to the name Chicoutepec, the exact character of which is in much doubt.

STRUCTURES IN THE SLATES OF NORTHEASTERN PENNSYLVANIA[2]

BY CHAS. H. BEHRE, JR.[3]

(*Abstract*)

The Martinsburg shale of Ordovician age, in Northampton County, Pennsylvania, yielded in 1922 approximately five-sixths of all the slate from Pennsylvania and over two-fifths of the commercial slate of the United States. The formation conformably overlies the Jacksonburg limestone and is separated by an angular unconformity from the superior Silurian sandstone and conglomerate. The Martinsburg shale is separable into three members—a lower, thin-bedded slate, probably of Trenton age and yielding banded, roofing slate; a middle member, mainly calcareous sandstone and thin-bedded clay-slate, of Eden age; and an upper, highly sericitic and more thick-bedded slate of lower Maysville age, worked for roofing, structural, and electrical slate and blackboard material. All members are probably estuarine in origin or laid down

[1] Introduced by J. A. Cushman.
[2] Presented with the permission of the State Geologist.
[3] Introduced by George H. Ashley.

in deltas, the sediments having been derived from the east. Some beds, although not more than two feet thick, are so persistent as to be traceable from quarry to quarry for five miles along the strike.

Two periods of diastrophism are recorded. The earlier (Taconic) movement produced slaty cleavage, close folding with great overturns and thrust-faults, and minor faults transverse to the axes of the folds. Taconic distortions were far greater than the ensuing post-Permian ones.

The later (post-Permian) diastrophic period produced distortion of slaty cleavage, interbed movements, and faulting along planes parallel to the axes of the earlier folds. Such fault-planes dip more steeply than the beds toward the troughs of the recumbent folds; the displacement dropped the beds down the dip of the fault-plane; the faulting appears to be "normal," though originating in thrusting and produced by too much bulging of the beds at the troughs. Such movements produced characteristic joints.

Striæ between beds are common and serve in some cases to indicate major structure. Grain has even greater constancy in strike than does cleavage. Regular jointing is well developed and very important in quarry operations.

Read in full from manuscript.

GEOLOGY OF LEVIS, QUEBEC

BY THOMAS H. CLARK[1]

(*Abstract*)

There are two formations exposed at Levis, the Levis and the Sillery, and both are of Beekmantown age. The Sillery is so complexly folded and faulted that no attempt to unravel its detailed structure has yet been successful. The Levis formation is folded and faulted, though not to such a degree as the Sillery; on previous maps it has been shown, on the mainland, as a unit, undifferentiated stratigraphically or areally. The writer has found it possible to divide the area occupied by this formation at Levis into three parts, mutually separated by faults, and stratigraphically distinct. The two fossiliferous series within the Levis formation (the graptolite-bearing shales and the limestone conglomerates) have no fossils in common, and there has previously been no means of correlating them. By fortunate discovery of fossiliferous localities the writer has been able to establish definitely the stratigraphic relation between the two series.

Presented in abstract extemporaneously.

Brief remarks were made by Mr. H. M. Ami.

PROPOSED STRATIGRAPHIC SECTION AND CODE

BY GEORGE H. ASHLEY

(*Abstract*)

Last summer the writer spent several days in the field interpreting the remarks of a highly trained stratigrapher to two of the country's leading geol-

[1] Introduced by Percy E. Raymond.

ogists. The incident emphasized to all the need of a simplified scheme of stratigraphic nomenclature applicable to North America, if not to the world.

The scheme presented consists of: (1) subdivision of Cambrian and subsequent time into "eras," "suberas," "ages," "periods," and "epochs"; "ages" based on subdivisions of correlative value in estimated duration and thickness of deposits (Silurian, Pennsylvanian, etcetera). "Ages," "periods," and "epochs" correspond with sedimentary names—"systems," "series," and "groups." The "groups" (for example, Hamilton) to be divided into "formations" (for example, Moscow shale) and the "formations" into "members," "zones," or "beds."

(2) The use of A, B, C, etcetera, to code the "ages" and a Dewey system to code the smaller subdivisions. Thus, fossil zone E 115 (or Devon. fossil zone —E 115—) designates the Spirifer modestus subzone (5, because the fifth from the bottom) of the Chonetes jerseyensis zone (1) of the Keyser group (1) of the Lower Devonian (E) (periods not coded).

The code may be used with or without other descriptive names. Thus, the Wilmore limestone may be identified by C 53; that is, as the third formation (from bottom) in the Trenton group (5) of the Mohawk or Middle Ordovician (C); or simply as Limestone C 53.

(3) The adoption of standard stratigraphic-section localities, using States (and counties where necessary) for formations or smaller subdivisions. Thus, the zone named above may be made definite by adding "Pa."; as E 115 Pa. If the Keyser were inconstant in Pennsylvania it might be necessary to add (Pa. 31) (31 for Huntingdon County, the 31st in alphabetical order).

Presented in abstract extemporaneously.

Discussion

Dr. J. J. Galloway: Stratigraphers are not agreed on the systems of the standard geologic column, much less the subdivisions and correlations of the smaller divisions. Until the time comes that general agreement is attained in nomenclature of the geologic column, a code can not be made; when agreement shall have been reached, it is unlikely that a code for formations will be needed, any more than a code is needed in the organic sciences instead of names for genera and species.

Prof. Charles Schuchert: It is good that Ashley is making earnest efforts to improve the terminology of the geologic column. The terms, as a rule, are a meaningless jumble of unrelated names, the sequence and geographic value of which no one can remember except in small part. It will not be difficult to invent a good and simple historical scheme, but it will be next to impossible to get the geologists of the world, or even those of America, to accept it.

The time terms of the generalized geologic column should consist only of those of the eras, suberas, periods or systems, and epochs or series. The endless local terms should be symbolized by numerals. For instance, the Coeymans limestone of the lower Devonian and of the Helderbergian series could be written thus:

L. Dev. 1. Helderbergian. (Figure 1 means basal series of the Devonian, and 2 the second formation of the series mentioned.)

Or, more briefly, Coeymans (L. Dev.).

Author's reply: In reply to Doctor Galloway, I feel that the time is here

when there should be organized, and preferably of this Society, a committee to see if some general agreement can not be attained in the nomenclature of the geologic column, particularly for the larger subdivisions.

It is not a matter of pride to geologists that we can not agree upon at least the larger features of this subject of stratigraphy. I am glad to see that Professor Schuchert agrees with my suggestion of the use of figures, particularly for the smaller subdivisions of the stratigraphic column.

In line with this, it may not be out of place to call attention to the fact that, as a result of my studies on coal classification, the subject has reached the point where a strong committee has been appointed to meet in February, in the hope that it will be possible to recommend a definite scheme of classification.

It might also be worth mentioning that the scheme here suggested has in part been previously made public through the Engineering and Mining Journal, and has been taken up by other technical journals, and is receiving wide publicity among engineers and others not geologists, who have occasion to use or refer to a geologic column. This column seems to have met the needs of people to such an extent that unless it is headed off by the geologists it seems likely to receive a widespread adoption.

Brief remarks were also made by Messrs. H. M. Ami and I. C. White.

SUGGESTIONS FOR THE IMPROVEMENT OF OUR GEOLOGIC TERMINOLOGY

BY ELIOT BLACKWELDER

(*Abstract*)

Geology has long been afflicted with a set of technical terms which is in some respects inadequate and in others confusing. Furthermore, there is much variation in the application of the terms. To the student trying to understand the subject, this state of affairs is disconcerting; and even the experienced geologist finds the condition an obstacle to the clear expression of his ideas and to the understanding of the reports of others.

In this paper the more important defects of the present system are indicated and some of the variations in usage set forth. As the condition is by no means irremediable, suggestions are made looking toward an improvement in the terms and the use of them. The writer believes that any complete new classification, however logical, is foredoomed to failure because of the inertia of long-established custom. Gradual amendments here and there can, however, be made if fully considered by a competent committee and endorsed by the Society.

In the absence of the author, this paper was read in full from manuscript by Prof. W. H. Twenhofel.

UPPER ORDOVICIAN AT TORONTO, ONTARIO

BY W. A. PARKS

(*Abstract*)

The strata at Toronto, Ontario, lying between the black Utica shales and the red Queenston shales are divisible into an upper series comparable with the

Richmond and a lower series showing affinities with both the Pulaski of New York and the Maysville of the Ohio district. It is proposed to name the lower division the *Dundas formation* and to divide it into four members in descending order as follows: *Credit, Humber, Davenport, Rosedale.*

The fauna of the Dundas formation, omitting annelids, conodonts, and some rare or doubtful forms, shows the following relationships:

	Species
Occurring only in the Pulaski or Lorraine of New York	8
Occurring only in the Maysville	26
Occurring only in the Richmond	20
Occurring in both Richmond and Maysville	7
Occurring in both the New York and Ohio fields	22
Occurring only in eastern Canada	11
Occurring only in the Eden	4
New species	24

While many species range throughout the formation, each member has its distinctive fauna; these faunas are as difficult to correlate as that of the formation as a whole.

The prevailing gray shales contain many hard, discontinuous layers. These are of two kinds—fossiliferous limestones and calcareous sandstones, generally without fossils. Both types vary from apparent beds to small lenses. Mere variation in sedimentation seems insufficient to account for these numerous, hard bands. It is suggested that they may be due to secondary infiltration of carbonate of lime into those parts of the general sediments best suited for its deposition.

Presented in abstract extemporaneously.

DISCUSSION

Prof. GEORGE H. CHADWICK: Structures similar to those described by Doctor Parks abound in the upper Devonian of western New York, with every gradation between huge septaria, flat, discontinuous "concretions" and continuous beds. In the Dunkirk black shale of this region, containing only plant stems (Linguliæ are reported) the septaria sometimes carry on their surface finely-preserved crinoid columns.

Brief remarks were also made by Prof. William H. Twenhofel, with reply by the author.

EARLIER SILURIAN FORMATIONS OF PENNSYLVANIA

BY CHARLES K. SWARTZ

(*Abstract*)

The earlier Silurian formations of Maryland have been correlated with the formations of western New York by their rich faunas. A series of studied sections will be communicated in this paper, showing that the earlier Silurian of Maryland is continuous with the beds of central and eastern Pennsylvania,

northern New Jersey, and eastern New York. Studies show that these beds extend eastward with ever-increasing shore facies. In going east, conglomerates replace first the lower, then the upper beds of the Tuscarora of Medinan age, passing into the Shawangunk of eastern New York.

The Clinton, including the Rochester, is clearly traceable to the Susquehanna River. East of this point the formation becomes increasingly arenaceous and barren. It is clearly recognizable as a distinct unit at the Lehigh River. Farther east it becomes still more arenaceous and appears to merge with the Shawangunk of New Jersey.

The red Bloomsburg interfingers in increasing degree with the Wills Creek and marine McKenzie eastward, where it occupies the entire interval of those formations, passing into the High Falls of New Jersey. The relation of the Bloomsburg to the Vernon Red Shale of western New York will also be pointed out. The problem presented by the red beds will be especially considered.

Presented in abstract extemporaneously.

DISCUSSION

Dr. GEORGE H. ASHLEY: Pennsylvania is to be congratulated on having such work as that by Doctor Swartz done within her borders. As a boy I made a similar study of the same age rocks at my old home town of Rochester, and found it possible to divide that section into a large number of thin elements on the basis of the fauna. Several species I found only in one horizon, usually abundant in that horizon, though the containing bed was only six inches or less thick. I became convinced that similar study, in this case covering years, would doubtless yield similar results elsewhere and must ultimately become the basis of all exact correlation.

Prof. GEORGE H. CHADWICK: It may be noted that of the Silurian white sandstone and pebble formations in central New York the one which extends farthest east in greatest strength, suggesting the Shawangunk, is the Herkimer sandstone of upper Clinton age.

Brief reply was made by the author.

KANSAS PERMIAN UNCONFORMITY[1]

BY GEORGE HALCOTT CHADWICK

(*Abstract*)

Discovery of a marked unconformity, with erosional contact, between the Marion and Chase stages of the reputed Permian in northern Kansas raises the question as to whether this break is the physical base of the true Permian in Kansas, especially as there is a decided lithologic and faunal change at this horizon.

Presented in abstract extemporaneously.

[1] By permission of the Empire Gas and Fuel Company.

ORISKANY LIMESTONE IN ILLINOIS

BY T. E. SAVAGE

(*Abstract*)

Limestone of Oriskany age is exposed over a small area near the west side of the Alto Pass quadrangle, in Union County, Illinois. This limestone overlies a bed of chert 125 feet thick, and is in turn overlain by Clear Creek chert, 300 feet in thickness. At the north this outcrop is terminated by a fault, trending northwest-southeast, which has brought Oriskany strata on the south up to the same level as those of Chester age on the north of the fault. The Oriskany strata dip generally toward the south and east, and in these directions they pass from sight beneath the overlying Clear Creek chert. It is not known how far this limestone extends eastward beneath the chert, but south of the Alto Pass quadrangle, in Illinois, the Oriskany had been entirely removed by erosion before the Clear Creek chert was deposited.

The Oriskany in Illinois is mostly a white, thick-bedded, coarsely crystalline limestone, having a thickness of 150, or more, feet. Near the middle part the limestone layers are interbedded with thin, irregular, chert bands. *Eatonia peculiaris*, *Spirifer murchisoni*, and a few other fossils occur sparingly throughout the middle and upper parts of the limestone, but the lower layers, through a thickness of 10 or 12 feet, are richly fossiliferous, containing *Leptostrophia magnifica*, *Plethorhyncha* cf. *barrandei*, *Rensselæria ovoides*, *Spirifer arenosus*, *Diaphorostoma ventricosum*, and many other characteristic upper Oriskany species.

Presented in abstract extemporaneously.

The session of Section I was discontinued at 5.50 o'clock.

JOINT SESSION OF THE GEOLOGICAL SOCIETY OF AMERICA AND THE MINERALOGICAL SOCIETY OF AMERICA

Dr. Edgar T. Wherry, President of the Mineralogical Society of America, presided at this session and Prof. L. C. Graton acted as Secretary.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

NEW HYDROLOGIC LABORATORY IN THE UNITED STATES GEOLOGICAL SURVEY

BY OSCAR E. MEINZER AND NORAH E. DOWELL[1]

(*Abstract*)

This paper is an announcement of a laboratory recently organized in the groundwater division of the United States Geological Survey for determining mechanical composition, porosity, moisture equivalent, permeability, and other

[1] Introduced by O. E. Meinzer.

hydrologic properties of water-bearing materials. An apparatus is being developed for determining permeability under hydraulic gradients as low as those found in nature.

Read in full from manuscript by senior author.

METEORITES FOUND IN PENNSYLVANIA

BY R. W. STONE

(*Abstract*)

Five meteorites have been found in Pennsylvania and, curiously, all of them are iron. The first one was discovered near Pittsburgh in 1850. It was wrought into a bar and lost sight of. The others were found at the following places: Mount Joy township, near Gettysburg, 1887; Bald Eagle Mountain, near Williamsport, 1891; Shrewsbury, York County, 1907; and New Baltimore, Somerset County, 1922. The smallest, that found on Bald Eagle Mountain, was about the size and shape of an adult human foot and weighed 7 pounds; and the Mount Joy, the third largest found in the United States, weighed 847 pounds.

The suggestion is made that two and possibly three of these meteorites are parts of the same fall, although found many miles apart.

Read in full from manuscript.

DISCUSSION

Dr. GEORGE P. MERRILL emphasized the apparently safe assumption that the fracture indicated a collision when the iron was sufficiently cold to be brittle.

EOLIAN ABRASION OF QUARTZ GRAINS

BY SAMUEL HOWELL KNIGHT[1]

(*Abstract*)

This paper treats of the abrasion of quartz grains in a migrating sand dune, as follows:

1. A quantitative determination of the abrasion of quartz grains of known size transported through known distances by air currents of known velocity.

2. A study of the changes in the shape of the grains during their abrasion.

A small dune (4 kilograms) of freshly crushed quartz grains of uniform size, was caused to migrate on an endless belt against an air current of known velocity. The movement of the belt was synchronized with the movement of the dune so that the position of the dune remained constant with respect to the apparatus. Thus the distance the dune migrated was equal to the distance the belt traveled. A four kilogram sample of quartz grains measuring 1 to 2 millimeters in diameter was blown a distance of fifty miles by a wind with an initial velocity of forty miles per hour. The reduction in size of the grains due to the abrasive action is briefly summarized as follows:

[1] Introduced by J. F. Kemp.

33.3 per cent (by weight) was reduced to less than 1 millimeter in the first two miles of travel.

51.0 per cent was reduced to less than 1 millimeter in 20 miles

34.5 per cent was reduced to less than .5 millimeter in 50 miles

Presented in abstract extemporaneously.

DISCUSSION

Mr. JOSEPH L. GILLSON: From your study of these wind-blown grains did you find any features by which you could recognize wind-blown grains as such in future study?

Reply by the author: The data presented in no way gives a measure of the time during which a sand grain may have been subjected to eolian abrasion.

Brief remarks were also made by Mr. Thompson.

MINERALOGY AND PETROGRAPHY OF FOSSIL BONE

BY AUSTIN F. ROGERS

(*Abstract*)

Fossil bones consist almost exclusively of the amorphous mineral collophane, which is also the principal constituent of phosphorite or so-called phosphate rock. The chemical composition of collophane is $3\,Ca_3(PO_4)_2.nCa(CO_3, F_2, O, SO_4).(H_2)$, the calcium being partially replaced by iron, aluminum, and magnesium. In this formula n varies between 1 and 2 and x is indefinite.

Fossil bone usually retains the original bone. Haversian canals, lacunæ, and canaliculi may usually be recognized.

The index of refraction of the collophane varies from 1.573 to 1.621, but is usually between 1.600 and 1.610. Although it is amorphous, collophane usually shows double refraction.

Minerals associated with the collophane of fossil bone include calcite, dolomite, aragonite, barite, quartz, chalcedony, opal, pyrite, wavellite, and rarely dahllite $[3\,Ca_3(PO_4)_2.CaCO_3]$. These minerals usually occur as cavity fillings, but the collophane is often replaced by calcite and very rarely by quartz.

The fossilization of bone consists of the filling of porous bone, from which the organic matter of the original bone has been removed by weathering, by calcium phosphate, calcium carbonate, etcetera.

There is little evidence of the migration of phosphatic solutions in and around fossil bones, but occasionally dahllite, wavellite, and collophane are found as cavity fillings.

The geological age of a fossil bone can not be determined from the character of the collophane.

Presented in abstract extemporaneously.

BAUXITE ASSOCIATED WITH SIDERITE

BY ERNEST F. BURCHARD

(*Abstract*)

Deposits of bauxite in relations that appear unusual have recently been discovered in northeastern Mississippi by J. W. Adams, of Tuscumbia, Alabama. The material occurs in the lower part of the Eocene near the contact of the lignitic sands and clays of the Ackerman formation and the Porters Creek clay (below), possibly an unconformable contact between the Wilcox and Midway groups.

The bauxite is distributed in fragmentary deposits in a broad arc from northeast to southeast, corresponding to the outcrop of the Ackerman beds through 10 counties. It varies in hardness from rock bauxite on the outcrop to clay-like material under cover. It is mostly pisolitic, the pisolites attaining a diameter of 1½ inches in places and forming masses resembling a pebbly conglomerate. Some of the bauxite is very ferruginous. In places the matrix cementing the pisolites is composed of fresh, brilliantly crystalline siderite, but in most of the material the siderite has altered to limonite. Interbedded with the bauxite are lenses more than one foot thick of massive siderite, altering on the surface to limonite.

The bauxite deposits occupy crests of hills, in places many acres in extent, and range in thickness from 2 to 15 feet.

Read in full from manuscript.

OCCURRENCE OF ITALITE NEAR GROTTA FERRATA, ALBAN HILLS

BY HENRY S. WASHINGTON

(*Abstract*)

The locality where the purely leucitic lava, italite, occurs is near Grotta Ferrata, in the Alban Hills, not at Rocca Monfina, as has been previously published. The occurrence is as blocks in beds of a peculiar tuff that contains many loose crystals of leucite, derived from the breaking up of underlying flows of italite. The italite is described and a new analysis is given. Analyses are also given of the pyroxene and of the biotite that make up some of the blocks included in the tuff. The relations of the italite to the other leucitic rocks of the Roman comagmatic region are pointed out.

Read by title.

ACMITE AND AEGIRITE

BY H. S. WASHINGTON AND H. E. MERWIN

(*Abstract*)

The acmite-aegirite series has been studied chemically and optically. These minerals are shown to be composed of acmite ($Na_2O.Fe_2O_3.4SiO_2$), diopside ($CaO.MgO.2SiO_2$), and hedenbergite ($CaO.FeO.2SiO_2$), in various proportions, with smaller amounts of jadeite and other molecules. Pure acmite is

colorless or slightly yellow. "Aegirite" is a mixture of acmite, diopside, and hedenbergite. It may best be called diopsidic acmite or diopside-acmite, and it is suggested that the term "aegirite" should be dropped from systematic mineral nomenclature. The characteristic green color is caused by the presence of both ferrous and ferric oxides. Large changes in refractive index and in optical dispersion accompany replacement of ferric oxide by alumina, and increasing diopside content changes the optical orientation.

Presented in abstract extemporaneously by Doctor Washington.

The Chair announced that this paper and the one immediately to follow by the same authors and Ralph W. G. Wyckoff, were so closely related that the discussion would be held until after the reading of the next paper.

X-RAY DIFFRACTION PATTERNS OF THE PYROXENES

BY RALPH W. G. WYCKOFF,[1] H. E. MERWIN, AND H. S. WASHINGTON

(*Abstract*)

Powder diffraction patterns have been prepared of representative, pyroxenic minerals. Taking likeness in their diffractions to indicate likeness in their crystal structures, it is shown, for instance, that enstatite is like klino-enstatite; that various augites have the crystal structure of diopside; that spodumene, wollastonite, babingtonite, and rhodonite are all unlike each other in their atomic arrangements and different from either klino-enstatite or diopside. As a result of such observations a regrouping of these minerals is suggested.

Presented in abstract extemporaneously by Mr. Wyckoff.

DISCUSSION

Mr. W. P. WHITE: In some unpublished determinations made thirteen years ago, thermal evidence previously offered for the different crystalline form of enstatite and clino-enstatite was checked up and found apparently erroneous. This result confirmed those who, from microscopic evidence, had asserted that the only difference in the two forms was a matter of twinning, and is now confirmed by the X-ray evidence just presented. The earlier thermal evidence was obtained by a very ingenious method by Allen and Clement, in which powder was dropped into a heated furnace and so raised very rapidly in temperature. A difference in the curves for the two materials was interpreted as heat of inversion. The very rapid heating gave great sensitiveness, but did not discriminate at all well between effects occurring at widely different places on the long-heating curve. It was found that there was an effect far below the supposed inversion, which could have given the effect that was attributed to that inversion by Allen and Clement, and that Allen and Clement had found the inversion in one case where they had not reached the temperature where the change from enstatite occurs. A method rivaling theirs in sensitiveness also failed to give any thermal effect corresponding to the supposed inversion.

[1] Introduced by H. S. Washington.

Mr. SAMUEL G. GORDON: Has there been any more confirmatory data regarding atomic isomorphism?

Author's reply to Mr. Gordon: Some more or less detailed studies using X-rays have been made of solid solutions. They are, however, largely limited to simple pairs of alkali halides and sulphates or of metals.

Brief remarks regarding the paper by H. S. Washington and H. E. Merwin were also made by Mr. Wyckoff.

CRYSTAL STRUCTURE OF DOLOMITE

BY RALPH W. G. WYCKOFF[1] AND H. E. MERWIN

(Abstract)

From Laue photographic observations on both pure dolomite and iron-rich dolomite it is shown that dolomite itself represents a definite chemical compound and not merely a solid solution of calcium and magnesium carbonates. Combining these measurements with reflection spectrum data from single crystal faces, the mode of atomic arrangement in dolomite is deduced. The effect on the dimensions of the crystal of an isomorphous replacement of magnesium by ferrous iron is also discussed.

Presented in abstract extemporaneously by Mr. Wyckoff.

Brief remarks were made by Dr. Henry S. Washington.

SAN FELIX AND SAN AMBROSIO: THEIR GEOLOGY AND PETROLOGY

BY BAILEY WILLIS AND H. S. WASHINGTON

(Abstract)

These two islands, situated in the Pacific in about latitude 26° south and longitude 80° west, were visited by Willis in the summer of 1923 in the course of his study of the Chilean earthquake of November, 1922. Both islands are wholly volcanic and, although there is no record of an eruption, there was some emanation of gas noted by Willis. San Felix is a low crescentic platform, composed of many flows of black "basalt," and ending in two hills composed of yellow tuff. The basaltic tuff of the highest hill contains many large blocks of a schistose trachyte. Chemical and microscopic study shows that the trachyte is much like the trachyte of Mas Afuera, about 500 miles to the south, on the same submarine ridge. The black pahoehoe "basalts," some of which are very fresh, prove to be varieties of nephelite basanite, like some of the basaltic rocks of Juan Fernandez. San Ambrosio, 16 kilometers east of San Felix, is also a volcanic remnant, much smaller than San Felix. Willis did not land on it, but the rocks (which have not yet been studied) appear to be basaltic. The occurrence and significance of trachytes and other alkalic rocks on the Pacific islands is discussed briefly.

Presented in abstract extemporaneously by Dr. Henry S. Washington.

[1] Introduced by H. S. Washington.

DISCUSSION

Mr. SAMUEL G. GORDON: What is the significance of the high TiO_2 content, and in what form is it present?

Author's reply to Mr. Gordon: The TiO_2 occurs in the lavas of Pacific regions up to 56 per cent at times. The TiO_2 is in the form of titaniferous magnetite.

Prof. AUSTIN F. ROGERS: In confirmation of Doctor Washington's view that soda-rich igneous rocks occur on the borders of continents, I might mention the fact that one of my students, Dr. H. V. Howe, has recently discovered a nepheline syenite on the coast of Oregon, the first found, I believe, west of the Continental Divide in the United States.

QUARTZ INVERSION IN CHALCEDONY

BY W. P. WHITE[1]

(*Abstract*)

Several properties of chalcedony, particularly its behavior with X-rays, indicate that it is, or contains, quartz or a modified form of quartz. Fenner's attempt to detect the quartz inversion at 573 degrees in chalcedony yielded inconclusive, apparently negative results. A renewed attempt has shown decisively that one sample of chalcedony exhibits the quartz inversion at 573 degrees, but with a different character from that encountered in ordinary quartz. The inversion begins at a lower temperature and ends at the usual place. Whether the total thermal effect is as great as with ordinary quartz—that is, whether chalcedony is all, or is only partly quartz—is not shown by the method used. Apparatus is now being constructed which should be able to settle this point.

Presented in abstract extemporaneously.

MOVING PICTURES OF THE VALLEY OF TEN THOUSAND SMOKES, ALASKA

BY C. N. FENNER

(*Abstract*)

On a trip made last summer to the Katmai region and the Valley of Ten Thousand Smokes a small moving-picture camera (the cine-kodak) was taken, and a number of films were obtained. These show, in a realistic manner, the action of the fumaroles and other typical features of the region. A few words of explanation were given.

Presented in abstract extemporaneously.

Brief remarks were made by Mr. Robert F. Griggs.

[1] Introduced by F. E. Wright.

STEREOSCOPIC PHOTOGRAPHY IN GEOLOGICAL FIELD-WORK

BY F. E. WRIGHT

(*Abstract*)

Photography to the geologist is simply a means to an end, namely, to record certain spacial relations between details of geological interest in the field. Photographs, sketches, and diagrams serve as note-book illustrations to aid the geologist in revisualizing and interpreting field data. In a geological photograph sharpness of detail, scale, and perspective are essential; if, in addition, a balanced rendering of the subject is possible, pictorial quality may be attained, but this factor, although highly desirable, is not essential. Perspective is secured by proper selection of a foreground, such that the eye is led, as in the field, from near objects to more distant objects. In many regions suitable foregrounds are difficult to find, and the photographs from such areas are generally flat and uninteresting. This may be overcome in part by coloring the print and thus adding contrast and with it the feeling of perspective. At best the apparent stereoscopic effect in a single photograph lags greatly behind that experienced in the field. Actual stereoscopic effect can be produced only by means of two photographs of the object from slightly different positions and viewed through a stereoscope. These photographs can be taken one after the other by the same camera. The most satisfactory effects are obtained when the distance between the two camera stations at right angles to the line of sight is between 1 and 5 per cent of the distance to the object.

Presented in abstract extemporaneously.

GEYSER REGION OF NEW ZEALAND

BY EDMUND OTIS HOVEY

(*Abstract*)

The geyser and hot-spring area of New Zealand is largely comprised within an area in the North Island about 150 miles long and 20 miles wide, stretching north-northeastward from Mount Ruapehu to the shores of the Bay of Plenty. There are many thousands of these hot springs, some of which are true geysers in their action and others are in the mud volcano condition. The chief known geysers are in the national park at Whakarewarewa, one and one-half miles south of Rotorua, the present railhead, and a great resort for tourists and health-seekers; at Wairakei, 50 miles south of Rotorua; and at Taupo, six miles farther to the southwest. Other less important ones exist in isolated places. The geysers of Whakarewarewa are irregular in their eruptive activity and most of them throw their columns of water to heights varying from 10 to 20 feet; but one of them, the great Wairoa geyser, erupts to a height of 80 to 90 feet. The geysers at Wairakei are small, but frequent in their periods of eruption, and some of them are strong in their ebullition. They are 10 or 12 in number, and none of them erupts to a height of more than 20 to 25 feet. The Crow's Nest geyser is an isolated vent on the bank of the Waikato River at Taupo. This erupts a small column of water to a

height of about 80 feet for about 20 minutes at intervals of approximately four hours. It is different from the other geysers noted, in that it has a cone 5 feet high and 8 to 10 feet in diameter. The great Waimangu geyser, which broke out in the line of the eruption rift of Tarawera after the volcanic outburst of 1886, is 18 miles southeast of Rotorua. It remained in periodic activity for about 30 years and threw up a mighty column of muddy water to heights of from 900 to 1,500 feet. Its last eruption took place in 1916, since which time its vent has been quiet. The neighboring Frying Pan Flat blew up in 1917 and has seemed to act as a safety valve for Waimaugu ever since.

The waters of the geyser and hot-spring area are highly mineralized. Most of them carry much silica in solution, and some of them show a considerable content of sodium carbonate. The commonest salts are sulphates of Na, K, Ca, Mg, Al, and Fe, chlorides of the same metals and bicarbonates of Na, Ca, and Mg. Besides SiO_2, H_2SO_4 is reported.

A pronounced feature of the thermal district is the abundance of hot mud springs, locally known as paint pots or porridge pots. These are places where the supply of mineralized thermal water and steam is just sufficient to cause chemical decomposition of the rock through which they rise, producing a finely divided or impalpable powder. This powder or mud is usually white or light gray in color, but often is yellow to pink and red or orange from contained iron oxides. There is a great cauldron of boiling mud at Tikitere, 12 miles northeast of Rotorua, and a mud volcano with a cone 15 to 20 feet high and about 18 feet in diameter at the top at Waiotapu, 30 miles south of Rotorua. Strong blow holes, from which issues only live steam, are known near Wairakei and on the northern slope of Tongariro, south of Lake Taupo. Other fumaroles are common throughout the district.

The volcanic activity, of which these thermal springs and geysers are a manifestation, began in Miocene time. It characterized the whole of the North Island. The lavas vary throughout the island, but the hot springs and geysers are all in a region now covered with a rhyolitic pumice.

Presented in full extemporaneously.

LAMINATED ANHYDRITE IN TEXAS

BY JOHAN AUGUST UDDEN

(*Abstract*)

A deposit of anhydrite, in part changed to gypsum, has recently been cored in a test for oil in Culberson County, Texas. The anhydrite for 1,264 feet shows a remarkably uniformly developed lamination. A preliminary study shows that the average thickness of the layers is about 1.63 millimeters. It shows also that the thickness of the layers varies in cycles. There appears to be one cycle of 6 or 7 laminations and another cycle of 11–13. Other cycles range from 240 to 420 laminations. Possibly still other cycles may be made out in a more complete study of the material. It is suggested that the layers may represent an annual period. If such is the case, it must have taken some three hundred thousand years for this deposit to accumulate.

Presented in abstract extemporaneously.

BROAD THRUST-FAULT IN THE CENTRAL APPALACHIANS

BY M. R. CAMPBELL AND R. J. HOLDEN

(*Abstract*)

In the central Appalachians, particularly in Montgomery, Pulaski, and Wythe counties, Virginia, there are certain features of areal geology for which a satisfactory structural explanation has been sought for many years. Recently such an explanation has been found.

Price Mountain, in Montgomery County, is a ridge of Mississippian sandstone and shale some 400 feet high, 7 miles long, and 2 miles wide, surrounded by Cambro-Ordovician limestone. Two miles southwest of this there is a second but smaller area, having the same physical relations except that the rocks of the central mass are of Devonian age, and 2 miles south of these two features there is another area of Devonian rocks about 8 miles long and 1 mile wide, surrounded by limestone. The structure of these younger formations is anticlinal and the older, surrounding limestone dips generally in conformity with the dips of the younger rocks. From 3 to 5 miles northwest of these fensters the Cambro-Ordovician limestone is thrust up onto the basal Mississippian, with both formations and the fault-plane dipping 20 to 50 degrees to the southeast.

The explanation of these relations is found in broad thrust-faulting, subsequent folding, and then erosion. The Cambro-Ordovician limestone has been thrust northwestward 7 miles or more over the younger Paleozoics, and erosion has removed the limestone from the areas where the Mississippian and Devonian rocks now appear, surrounded by the limestone.

This fault has been traced for a total distance of 130 miles. At places on its trace there is evidence supporting its broad character. In Pulaski and Wythe counties, Draper, Tract, and Cove mountains constitute a great embayment of Paleozoic formations partly surrounded by the Cambro-Ordovician limestone, and probably in recent geologic time Draper Mountain was completely surrounded and formed another anticlinal fenster.

The anticlinal character of the various fensters, noted above, and the conformable structure of the surrounding limestone, together with the presence of a belt of Cambrian limestone on the north side of Draper Mountain infolded in Devonian and Carboniferous sandstone, indicate that there has been a period of folding since the faulting took place.

In western Virginia there is thus an overthrust fault 130 miles long, which has a maximum known thrust of 9 miles. This faulting occurred after the main deformation of the region and there has been some folding since it took place.

Presented in abstract extemporaneously by Mr. Holden.

DISCUSSION

Prof. J. A. UDDEN asked if any drill holes had been put down to determine depth at which coal might lie under the overthrust rocks.

Author's reply: Drill holes are now being made.

PENNSYLVANIAN CORRELATION IN NORTHWESTERN ILLINOIS

BY HAROLD E. CULVER[1]

(*Abstract*)

Following the discovery of faunal evidence suggesting a possible miscorrelation in the Pennsylvanian in northwestern Illinois, a study of the methods of the earlier stratigraphic work was begun. The criteria for correlation are noted and evaluated and a need for more reliable data shown. A new line of evidence, based on a limited lithologic sequence, which is traceable over the area, is offered as a better means of correlation. These new data favor the conception of an extension of the Upper Pennsylvanian west of the limit heretofore recognized.

Presented in abstract extemporaneously.

The session of Section II was discontinued at 6 o'clock.

ANNUAL DINNER

At 7.30 the Society and its visitors and guests, together with members of the Paleontological Society, the Mineralogical Society of America, and the Society of Economic Geologists, assembled at Rauscher's Hall for the annual dinner. There was a very large attendance, about 300 persons being present, and the excellent appointments of the place, together with its good service and the extraordinarily clever entertainment provided by the Pick and Hammer Club, made this an unique occasion and one long to be remembered in the history of the Society.

The formalities of the occasion were looked after by President White, while Mr. Gerald F. Loughlin, chairman of the local committee and leader of the Pick and Hammer Operatic Society, together with his associates, had in charge the chief feature of entertainment and played the parts assigned to them in enviable manner.

President White introduced Professor Kemp as toastmaster, who explained the limitations under which all of the contributions to the entertainment of the evening would be carried out. Responses were called for and distributed through the intervals between the courses of the dinner by Professors Lawson, Adams, Leith, and Merriam.

At an appropriate time, early in the course of the dinner, President White took occasion to make formal presentation of the tribute of appreciation prepared by the Council of the Society for presentation to Prof. William North Rice, one of the most beloved of the members of long service known to geology in America, and to Dr. Edmund Otis Hovey, who was for sixteen years Secretary of the Society.

[1] Introduced by E. S. Bastin.

PRESENTATION OF TESTIMONIALS

PRESENTATION OF THE WILLIAM NORTH RICE TESTIMONIAL

Members and Guests of the Society:

Geologists in general are a generation of men little given to emotion. Nevertheless, they sometimes rise spontaneously in acclamation of their appreciation of high scientific achievement, of character inspiring their emulation, or of exemplary professional conduct. It is in our minds and in our hearts this evening to pay homage of affection, of high esteem and of admiration, to one of our elders, William North Rice. I am but the mouthpiece of the Geological Society of America and the conveyor of the unanimous sentiments of its membership when I present the document, which reads as follows:

The Geological Society of America, Assembled in Annual Session, Washington, D. C., December 28, 1923

Doctor William North Rice, Professor Emeritus of Geology of Wesleyan University, Fellow of the Geological Society of America since 1890

DEAR PROFESSOR RICE: At the meeting of the Council of the Geological Society of America, held at the close of the annual meeting in Ann Arbor, Michigan, December 30, 1922, it was resolved unanimously that a testimonial should be prepared and presented to you at the next annual meeting. A committee was appointed, who reported to the Council the following October, and was instructed to place in final form the testimonial which is hereby conveyed to you.

DAVID WHITE, *President.*
CHARLES P. BERKEY, *Secretary.*

TESTIMONIAL

On November 21, 1923, Prof. William North Rice reached the ripe age of seventy-eight. In June, 1918, he completed fifty years of continuous service as Professor of Geology in Wesleyan University, a length of service seldom equalled. He graduated at Wesleyan University in 1865, when he was not quite twenty years of age. He took the degree of Doctor of Philosophy at Yale two years later, and then studied for a year in the University of Berlin. Returning to America, he began his work at Wesleyan in 1868.

Professor Rice's student and teaching years cover the transition period between the old-time college instruction of a very general character and the newer university training, with the demand for exact knowledge and for experience in field and laboratory. In his Vice-Presidential address before Section E of the American Association for the Advancement of Science, in 1905, he recalled in a most interesting and striking manner the views of the older school, represented by Edward Hitchcock, Benjamin Silliman, and their contemporaries, personally known to his youth, as contrasted with the teachings of the later geologists, familiar in his riper years. In his rôle of interpreter he has played a most useful part.

Not alone as Professor, but also as Assistant on the United States Geological Survey, as Superintendent of the Connecticut Geological and Natural

History Survey for the thirteen years 1903 to 1916, and as Lecturer in sister institutions, Professor Rice has served his day and generation. To many anxious souls, troubled over the apparent conflict of modern science with cherished religious beliefs, he has brought the healing comfort of a clear, sympathetic and courageous thinker. In the Geological Society of America he has been peculiarly and exceptionally beloved, and his addresses at several of the banquets are remembered and cherished as the bright, particular gems of the evening. At the great banquet held last December in Ann Arbor, the largest in the history of the Society, this was outstandingly true; and the Council of the Society resolved to give concrete expression to its own feelings and those of the great body of the Fellowship in preparing and presenting to Professor Rice this testimonial, in which all could convey to him the deep affection and respect in which he is universally held. It is our desire, also, to convey the earnest wish that for many years to come our meetings may be graced and adorned by his presence.

JAMES F. KEMP, *Chairman.*
CHARLES P. BERKEY.
LEWIS G. WESTGATE.

In a sense this testimonial is a material symbol of a deeper feeling. It is a written tribute to a man the more indelible story of whose accomplishments will in a later period be found in the bulletins of the Society and the reports of the Geologic Commission of the State of Connecticut, in the instructional literature of our profession, and of Wesleyan University in particular, and in the records of the conference of a church. One can in mind picture this document as in a later period reposing among the library treasures of some one by the name of Rice, or, it may be, in the University Library, where it will remind future students of a one-time head of the Geologic Department who, larger than his department, was an inspiration to every student; beloved by pupils, associates, and colleagues; steadfast in his geology; firm in a consistent faith, and unflinching in his love of and search for truth.

RESPONSE OF WILLIAM NORTH RICE

I am indeed grateful for the kind words of the testimonial, coming from men whose geological work I so highly respect. I am fully aware that my own work in geological investigation has been insignificant. My work has been mainly that of a teacher, an expounder of the results of the investigations of other men. In the half century that has passed, I have learned much and unlearned much. The geology of today is very different from the geology which I taught a half century ago; and one is almost dazed by the rapid succession of new discoveries. During these days in Washington I have learned much, as I have sat at the feet of the younger men who are active today in the field of investigation.

As I look back over a career which must be nearly ended, I am inclined to believe that my best work has been in the study of the relations between science and religion. In our scientific work we study the relations of coexistence or succession of phenomena, and thus trace backward with more or less of probability the history of our world and of the universe of which it is a part.

In that study we have nothing to do with efficient or with final causes. Science has no answer to the question whether the universe is dead and soulless or is the expression of intelligence and ethical purpose. When scientific men recognize the limits of science, and when theologians view the old anthropomorphic conceptions of God as only symbolic of Deity eternally imminent in an eternal universe, the essential harmony of science and religion is revealed. I feel most deeply grateful for the words in which my comrades in scientific study have expressed their sympathy in what seems to me to have been the most important work of my life.

PRESENTATION OF THE EDMUND OTIS HOVEY TESTIMONIAL

Fellow-members and Friends:

The Geological Society of America is nearing the half-century mark, for it is thirty-five years since it was founded at Ithaca. Since 1888 it has grown to become the preeminent geological society of the world. The election of yesterday brought the number to a little over half a thousand. Its standard of membership is the highest and it embraces all the leaders of our generation in North American geology. Its great series of bulletins embrace major contributions in all branches of our science. It is a great Society; we know it, and are proud of it.

This splendid accomplishment is, according to the organization of our Society, very largely the work of its secretaries, as we all know. Presidents come and presidents go; members of the Council change in rapid rotation, but the Secretary goes on like the brook, and it is to his guiding hand, his wisdom, his good judgment, his tact, his untiring effort, and his vision that our success is largely due. A great part of the prosperity, the prestige, and the productivity of the Geological Society of America has been achieved during the period of sixteen years of the secretaryship of Edmund Otis Hovey. Recognizing this great service to geology, as well as to itself, the Geological Society of America presents to Doctor Hovey this inscribed tribute, which says:

The Geological Society of America, Assembled in Annual Session, Washington, D. C., December 28, 1923

At the last annual meeting, held in Ann Arbor, Michigan, December, 1922, Doctor Edmund Otis Hovey, Secretary of the Society since December, 1906, at his own wish, retired from office. Acting on the suggestion of the Council, President Schuchert appointed a committee to prepare an appropriate resolution of appreciation.

This resolution has become by unanimous acceptance the formal tribute of the Society to his faithful and long service, and the succeeding Council has voted to put this testimonial in permanent form.

DAVID WHITE, *President.*
CHARLES P. BERKEY, *Secretary.*

TESTIMONIAL

Doctor Hovey has held for sixteen years the responsible and exacting office of Secretary. During all this time he has shown exceptional devotion and

unsparing fidelity in the discharge of the duties of his office. Under his tenure the Society has maintained the high ideals with which it started on its career thirty-four years ago, and has done so in no small degree because of the influence and sound judgment of its Secretary. The publications have also held true to the exalted standards now long established.

Doctor Hovey has witnessed during his official life, and has shared in carrying through, at least one important change in policy and organization—that relating to the affiliated societies. The Paleontological Society became the first affiliate, the Mineralogical Society the second, and last year the Society of Economic Geologists joined the group. By this wise arrangement excessive and weakening subdivisions is avoided, while a large degree of practicable unity is maintained. The Geological Society desires to express and record upon its minutes a warm and cordial expression of appreciation of the unselfish service given by its retiring Secretary, and to wish him the successful completion of the scientific labors to which he desires to give his entire efforts and attention.

JAMES F. KEMP, *Chairman.*
JOHN M. CLARKE.
R. A. F. PENROSE, JR.

In the presentation of this testimonial, we extend our affectionate greetings to a geologist of many interests, ranging from the tropical volcano to the polar ice-cap, to an unfailing helper of others, to a comrade-in-arms, and to a friend.

RESPONSE OF EDMUND OTIS HOVEY

Mr. President and Fellows of the Geological Society of America:

This address of President White and this beautiful gift almost take my breath away. At the annual dinner a year ago at Ann Arbor the Society made me very happy by adopting the resolution which has just been read again in your hearing and presenting me with a beautiful silver loving cup. During the present year Secretary Berkey has told me that the resolution was to be engrossed and that I should get it some day. I supposed that it would be done in some plain but suitable style and would be handed or sent to me without special comment. So I was still admiring the beautiful testimonial which you have bestowed upon our beloved colleague, Professor Rice, and President White had gotten well started upon his second address before I realized that I was the object of his remarks, and he concluded his discourse by handing me an equally beautiful example of the engrosser's art. This is so sudden that I can scarcely find words in which to express my deep appreciation of the kind words in which our President has clothed his transmission of your gift and the touching resolution in which the present Council has indorsed the act of its predecessor. The elegant form in which the resolutions have been preserved will be an enduring memento of sixteen years of loving and happy service.

AFTER-DINNER ENTERTAINMENT

At the conclusion of the dinner the tables were removed, so that the seating of the hall could be rearranged to better advantage for the enter-

tainment provided by the Pick and Hammer Club, representing the local committee. This entertainment, in the form of an operetta, with well-known geologists for the principal characters and geologic problems as a foundation for its movement and inspiration, was hugely enjoyed by every one. It was universally considered a most clever piece of work and particularly suitable to the occasion.

After the operetta the hall was again cleared and opportunity was given for dancing to a late hour.

Session of Saturday Morning, December 29, 1923

The session of Saturday morning was a joint session of the Geological Society of America and the Mineralogical Society of America, President White, of the Geological Society, presiding, and was called to order at 9 o'clock.

TITLES AND ABSTRACTS OF PAPERS AND DISCUSSIONS THEREON

PHYSIOGRAPHIC HISTORY OF THE SAN LUIS VALLEY OF COLORADO AND NEW MEXICO[1]

BY WALLACE W. ATWOOD AND KIRTLEY F. MATHER

(*Abstract*)

East of the San Juan Mountains in Colorado the surface covering of the San Luis Valley is alluvial waste. Beneath that mantle of loose material there are flows of basaltic lava, referred to in preliminary field notes as the Hinsdale basalt. Beneath the Hinsdale basalt, as exposed in the gorge of the Rio Grande, there are thick deposits of stream gravels. Traced westwardly, the Hinsdale basalts and the underlying gravels rise on the slopes of the San Juan Mountains. They reach quite to the summit in the eastern portion of the range; and there the gravels underneath the basalts rest on the summit peneplain of the San Juan Mountains, described by the authors of this paper in various previous publications. These relationships indicate a depression of the eastern part of the range and in the San Luis Valley trough, while the central and western portion of the San Juan Mountains has been rising through late Tertiary and Quaternary times. Southward from the Colorado line the gravel deposits beneath the Hinsdale basalts become exceedingly widespread and very thick. Here the waste which came from the San Juan Mountain area during long periods of erosion accumulated. The late geologic or physiographic histories of the San Juan area and the San Luis Valley are evidently intimately associated.

Presented in abstract extemporaneously.

[1] Presented with the permission of the Director of the United States Geological Survey.

Discussion

Dr. William C. Alden: I would like to point out the close similarity between the phenomena described by Doctor Atwood and those which I described Thursday afternoon for Montana and Wyoming, except that we have not at the north the "reverse" phenomena described for the Grand Canyon region. The ancient wide mountain valleys, in the bottoms of which are cut the inner canyons, are duplicated on Clark Fork of the Yellowstone in Wyoming. The glaciation of these wide, high-level valleys and the correlated "boulder mesas" are the oldest features that I have evidence of being Pleistocene. The old glacial drift probably corresponds to the Nebraskan stage, and the canyons were cut before the Wisconsin stage of glaciation came on. The phenomena seem practically identical in character at the north and south, although we can not yet, perhaps, make precise correlations. In the Yellowstone Valley, above Livingston, the last of the basalt flows overlies about 80 feet of stream gravel, which may correlate with the third or lowest terrace. Below the gravel are the tilted and eroded "Bozeman" lake beds.

Author's reply: In replying to Doctor Alden's question, it is a pleasure to report that in following out the history of Alpine glaciation in the San Juan Mountains we have found evidence in the field that shows very clearly the relationship of the three successive stages of glaciation during the Pleistocene time to the stages of dissection by streams.

The broad outer valleys in the San Juan region, that were carved out of the Summit peneplain of Pliocene age, had reached maturity, and probably the entire region had been dissected to a mature stage for a mountain area, when the first of the Pleistocene glaciers formed in the mountains. Those glaciers were much more extensive than any of the later Alpine glaciers of the region. They extended far beyond the limits of the range and must have formed piedmont glaciers at the base of the mountains. We have called the drift deposits of that stage the Cerro formation, a name chosen from a locality on Cerro Summit, where the exposures are excellent and rather typical.

The two later, well determined stages of Pleistocene glaciers are known as the Durango and Wisconsin stages, and the ice during each of these stages advanced through the great canyons of the range that were developed after the Cerro stage had been completed and before the Durango ice formed. These canyons were of course deepened during the Durango and Wisconsin ice stages, as well as in the interglacial stage between the Durango and the Wisconsin ice, and they have been deepened still more since the Wisconsin ice disappeared.

Prof. Andrew C. Lawson: The San Juan Mountains, being relieved of load by erosion, should be rising, owing to compensation in depth, if we are to apply the principle of isostasy. The flanks, on the other hand, should be sinking, giving rise to a structural trough deeply filled with sediments, and a zone of shearing at the base of the mountains. The expectation of the theory appears not to be realized in the facts described in the paper, as indicated in the cross-sections.

Mr. W. P. White: Reference having been made to isostatic movements, I should like to express the hope that several gravity stations may be established in this region, where, according to hope and expectations, apparatus is at hand for rapid and relatively inexpensive, gravity observations. The region

is a most interesting one from this standpoint. The analogies least expected are, that stations on the uplifted and eroded pre-Cambrian will almost certainly give plus anomalies unless the rocks are lighter than expected, while the valley region is likely to show anomalies with the minus sign. In other words, the uplift or positive area will probably reflect overweight if one regards only the face value of anomalies, while the region of subsidence may present the superficial aspect of lack of loading.

FUMAROLIC INCRUSTATIONS OF THE KATMAI REGION

BY E. G. ZIES [1]

(*Abstract*)

Magnetite, salmiac, the silico fluorides of the alkaline bases and gypsum are the only well-defined minerals found in the incrustations.

Chemical analysis shows the presence of fluorides, chlorides, sulphides, and sulphates. The relatively high fluorine content is one of the outstanding characteristics of the incrustations. Analysis also revealed the presence of lead, copper, molybdenum, tin, antimony, manganese, and zinc. Lead and zinc occur more frequently than the others and vary in amount from 0.01 to 0.40 per cent. The others are less common, but in some cases are present to the extent of 0.02 per cent. The spectroscope revealed the presence of germanium.

The association of halides, sulphides, and metals will be discussed; also the probable method by which they were removed from the magma below and deposited in the cooler region above.

Presented in abstract extemporaneously.

Brief remarks were made by Messrs. Robert F. Griggs and L. C. Graton, with reply by the author.

THE SYSTEM: Al_2O_3–SiO_2

BY N. L. BOWEN

(*Abstract*)

Corundum is frequently set free from material containing sillimanite when such material is acted on by a liquid, whether it be a natural liquid (magma) acting on argillaceous sediments or certain artificial liquids (glass melts) acting on similar materials when made up into refractories. This setting-free of corundum led us to suspect that sillimanite melts incongruently, breaking up into corundum and liquid. Heating tests on both natural sillimanite and an artificial mixture of the composition Al_2O_3–SiO_2 confirmed this hypothesis. At the same time it was found that the crystals which have been called artificial sillimanite, though remarkably similar to natural sillimanite optically and crystallographically, have not the composition of sillimanite but show the ratio $3Al_2O_3 : 2SiO_2$. These facts necessitate a revision of the system Al_2O_3–SiO_2 which is here presented and which brings out many points of importance to petrology and to the ceramic arts.

Presented in abstract extemporaneously.

[1] Introduced by F. E. Wright.

The Chair announced that the papers by Doctor Bowen and Mr. J. W. Greig, immediately to follow, were so closely related that the discussion would be held until after the reading of the next paper.

IMMISCIBILITY IN SILICATE MELTS

BY J. W. GREIG [1]

(*Abstract*)

In the system MgO–SiO_2 the part of the cristobalite liquidus which has been investigated is so steep that an ordinary extrapolation of the curve would carry it far above the melting point of cristobalite. This indicates that this curve is either of a very unusual shape, or actually discontinuous, due to the mixtures rich in silica, forming two immiscible liquids. Silica-rich mixtures of lime and silica were found to behave similarly. Further work showed a region of immiscibility in both these cases. An investigation of the miscibility of silica with lime, magnesia, alumina, soda, potash, strontia, and baria is now in progress. This is a preliminary paper giving the results so far obtained.

Presented in abstract extemporaneously.

Brief remarks regarding this paper and the one preceding, by Dr. N. L. Bowen, were made by Prof. R. A. Daly, with reply by Mr. Greig.

DOLOMITIZATION IN SOUTHERN NEVADA

BY D. F. HEWETT

(*Abstract*)

Limestones of the upper Paleozoic section are extensively altered to dolomite in the southern end of Spring Mountain Range. The pre-Devonic rocks were originally largely magnesian limestone and dolomite, whereas the Devonian, Mississippian, and Pennsylvanian rocks were largely pure limestone and are now widely altered to dolomite.

In early Tertiary time the beds were folded, and numerous thrust-faults developed; these were followed by the intrusion of small bodies of orthoclase porphyry and later by a series of early normal faults and the deposition of lead and zinc deposits. Dolomitization of the Devonian and later limestones began after the folding, and continued with decreasing intensity through the period of ore deposition. Two later systems of faults were not accompanied by dolomitization. In several small areas late Tertiary, fine-grained, intrusive rocks produced dolomite locally and altered earlier dolomite to a dolomite-brucite rock.

Dolomitization was largely effected without appreciable shrinkage in volume. The solutions that accomplished it were probably related to the intrusions of orthoclase porphyry. It is clearly a type of hydrothermal alteration.

Presented in abstract extemporaneously.

[1] Introduced by N. L. Bowen.

Discussion

Prof. James F. Kemp remarked the similarity between the areas described by Mr. Hewett and the old camp of Aspen, in Colorado. At Aspen, the lower part of the Leadville, pure calcite limestone is changed to brown dolomite, with ore favoring the contact. These relations were recognized by the miners early in the development of the camp and are described at length by J. E. Spurr in the Monograph on Aspen, published in 1899. The relations of the limestone and dolomite are similar to those described by Mr. Hewett, where the contact rather sharply follows a bedding plane. Speaking from memory of an extended visit in 1888, there were few, if any, such irregular relations then exposed as in the Nevada instances. In comparison of the dolomitization with replacement processes in which ore is introduced, several mining geologists, as well as the speaker, have noted that fine-grained limestones yield more readily than coarsely crystalline ones, apparently because of the greater ratio of surface to mass in the small particles as compared with the large ones.

Dr. R. B. Sosman: The attention of geologists has perhaps not yet been called to the remarkable results of the experiments of Hele-Shaw[1] with his "stream-line filter." This consists of a great number of sheets of slightly crinkled paper, with a few main channels perpendicular to these sheets, but passing only part way through. A solution forced through the mass under pressure, therefore, flows freely through the large openings and then perpendicularly by way of the narrow spaces, spaces of the order of magnitude of the mean free path in a gas. The filter produces some very remarkable results, such as the removal of colloids, separation of emulsions, extraction of colors, even removal of salt from a salt solution. The flow of liquids in capillary spaces is evidently accompanied by phenomena not yet clearly understood. It is very probable that some of the phenomena of replacement in nature are of this class and are not reactions which can be represented by the familiar balanced equations of chemistry.

Prof. L. C. Graton inquired if any measurements had been made to determine whether the replacement of limestone by dolomite was actually accompanied by a decrease in volume as the conventional chemical reaction would indicate, since even in the absence of slumping a volume shrinkage might result, but be distributed through the dolomite as a small scale porosity.

Remarks were also made by Prof. Chester R. Longwell, with reply by the author.

SULPHATE MINERALS FORMED BY OXIDATION OF PYRITIC ORE AT BISBEE, ARIZONA

BY H. E. MERWIN, AUGUSTUS LOCKE, AND E. POSNJAK[2]

(*Abstract*)

The walls of some mine drifts are covered with crystalline crusts of sulphates formed by evaporation of capillary water. Nearest the pyritic wall

[1] Proc. Royal Soc. London, 1923.
[2] Introduced by H. E. Merwin.

are acid and highly ferrous sulphates containing also magnesia and potash; next are normal ferric sulphates; and near the surface are normal and basic and moderately ferrous and highly cupric sulphates. Deductions concerning the solutions are made by reference to the equilibrium diagram of the system Fe_2O_3–SO_3–H_2O.

Presented in abstract extemporaneously by the senior author.

Discussion

Dr. R. C. Wells: This paper is of interest for several reasons. It shows what a wealth of minerals may be unearthed in such evaporation deposits when the minerals are carefully separated. The nature of the minerals proves that the acidity persisted for some distance from its origin, as otherwise the compounds would have been basic salts. Evidently these are only part of the possible series, as many basic sulphates of iron and copper have been described, although some that have been described were doubtless mixtures rather than definite species.

Mr. Samuel G. Gordon: Several years ago I gathered a series of sulphate minerals in an abandoned stope at Cerro de Pasco, Peru. Stalactites of chalcanthite, and more commonly an iron-copper hydrous sulphate, hung from the roof of the stope. On the floor were numerous stalagmites of rhomboclase, about the base of which were crusts of roemerite. There were a few small, white stalagmites of a white, hydrous, magnesium sulphate. Elsewhere in the mine were acicular efflorescences of goslarite.

Mr. R. J. Holden: As there are a large number of iron sulphates, as many of them are unstable, and as in slow-moving streams iron sulphates occur which near the surface of the water in sunlight are red, and which at a depth of a foot in sunlight and at the surface in the absence of sunlight are darker in color, it seems appropriate to inquire if light has any effect on composition.

Author's reply to Doctor Merwin: I have no knowledge of the effect of light.

PRIMARY NATIVE SILVER ORES OF SOUTH LORRAINE NEAR COBALT, ONTARIO

BY EDSON S. BASTIN

(*Abstract*)

Field and office studies of the ores of the Frontier mine show that nearly all of the native silver is a late primary mineral. Native silver is the principal valuable mineral of the ores. Most of it was deposited late in the primary mineralization. As the nickel and cobalt arsenides prevailingly show their own characteristic crystal faces against the silver, the latter can not have replaced them. What appear at first sight to be replacement veins of silver and calcite traversing the arsenides are shown to be fillings of minute rifts developed during crystallization.

Presented in abstract extemporaneously.

Discussion

Prof. T. L. Walker: According to my observations on polished vein specimens from Cobalt, most of the silver occurs in dendritic structures in which the silver forms the central part of the structures, links of arsenides surrounding circular or oval areas of silver. I should be glad to know if Doctor Bastin regards this type of silver as primary.

Brief remarks were also made by Messrs. A. C. Lane and R. C. Wells, with reply by the author.

PARAGENESIS OF THE BOLIVIAN SILVER-TIN ORES

BY GEORGE M. HALL[1]

(*Abstract*)

The ores range from tin ores in the Quimsa Cruz Mountains to silver-tin, like those of Oruro, Potosi, and Colquechaca, to silver ore at Pulacayo. The mineralogy of the ores consequently ranges from that of the typical deep-seated tin vein type to that of silver deposits in the intermediate zone. Tourmaline, topaz, apatite, arsenopyrite, and cassiterite were the earliest minerals deposited and the silver-bearing sulphantimonides were the latest. There were not two periods of mineralization, but the sequence was continuous and expresses a continuous change in conditions.

Read in abstract from manuscript.

Discussion

Mr. Samuel G. Gordon (in regard to statement that apatite was noted but once): Apatite was found by me at Pulacarjo. Phosphate minerals are very common in the mines south of Oruro. These include vivianite, warellite, and the rarer angelite, vauxite, and paravauxite. They have been usually overlooked, as they occur in small vugs and veins, representing the last stage of crystallization.

Prof. Waldemar Lindgren: Fluorite is not so far, I believe, recorded from Bolivia tin deposits. However, there is one place at Chacaltaya, not far from La Paz, where fluorite occurs in cassiterite veins in considerable quantities. The succession of minerals is tourmaline, quartz, pyrite, cassiterite, stannite, and fluorite, fluorite being the latest mineral.

Brief remarks were also made by Prof. L. C. Graton.

NATIVE SILVER IN AN IRON MINE

BY ALFRED C. LANE

(*Abstract*)

A specimen from the number 2 shaft of the Inland Steel Company, Cuyana Range, Crosby, Minnesota, was shown. It occurred in a thin (.02 inch) seam,

[1] Introduced by Joseph T. Singewald, Jr.

12 by 6 feet, dipping about 50 degrees, running from a rich 65 per cent hematite ore into the footwall material of altered green diorite, according to R. L. Wahl, Assistant Superintendent, to whom is due notes of the occurrence.

The first description of a similar occurrence was by Denton, Eby, and Berkey.[1]

This was from the Montana shaft, Soudan Mine, Vermillion Range. A. E. Seaman notes it also south of Lake Superior at the Great Western Mine, Crystal Falls; Cuff Mine, Iron Mountain; Chicagon Mine, Iron River. It is always rare and in thin sheets like the leaf copper in the joints of basalts. To the excellent description of Berkey little can be added, though a polished section prepared in the laboratory of L. C. Graton, showing specks of copper in the adjacent hematite and no bleaching, was shown.

The paragenesis is not unlike that of the primary silver described in an immediately preceding paper by Bastin, and the author of this paper agreed, with Berkey and Bastin, that the metal was the primary ore. Among the possible origins suggested by Berkey, the writer of this note favored an origin by downward migration from formerly overlying Keweenawan formation, and suggested that both silver and copper might be carried as chlorides, as silver chloride is soluble in salt water. A sample of water from the bottom of the Montreal Iron Mine of the Gogebic Range, analyzed by R. C. Wells in the United States Geological Survey Laboratory, is of the same calcium chloride type as the deep mine-waters of the copper mines of Keweenaw Point; and, according to Coleman, contains 11 parts per million of copper.

Presented in abstract extemporaneously, with specimens.

Brief remarks were made by Mr. A. L. Parsons.

ADDRESS OF THE RETIRING PRESIDENT OF THE MINERALOGICAL SOCIETY OF AMERICA

At this point, 12 o'clock, arrangements had been made for the presentation of the address of Dr. Edgar T. Wherry, retiring President of the Mineralogical Society of America: Title, "Surface of a crystal." This paper will be printed in full in a later number of volume 35 of the Bulletin.

At the close of this address the local committee made announcements covering special arrangements made for the entertainment of visitors and guests for the afternoon, as well as arrangements for visitors to laboratories and research institutions and for field trips scheduled for the afternoon and for the following morning.

President White, in bringing the meeting to a close, spoke briefly of the operation of the program and the excellent cooperation of the members of the Society, and particularly those responsible for presenting the scientific papers, enabling the sessions to be carried through almost pre-

[1] Proc. Lake Superior Mining Inst., vol. iv, 1896, pp. 69-79.

cisely on scheduled time. He remarked on the difficulty of managing so heavy a program with full opportunity for discussion, but called attention to the fact that a live interest was shown in a very large number of the papers by the numerous brief remarks that it was possible to make in the time allotted. Considering the general satisfaction given by the definiteness of place and time that each part of the program held, he recommended that a similar method of organizing the program be used by the new Program Committee another year.

RESOLUTION OF THANKS

A resolution was then presented by Professor Westgate, with unanimous approval of the session, as follows:

Washington, the home of the Carnegie Institution, the National Museum, and the United States Geological Survey, has an unusual attraction for the Fellows of the Geological Society of America, and we look forward to meeting here with the liveliest and most pleasurable anticipations. This week these anticipations have been more than realized. As we close one of the largest and best meetings of the Society, we wish to place on record our hearty appreciation of, and thanks for, the comprehensive, untiring, and completely successful efforts of our hosts, in particular the Geological Society of Washington, the Pick and Hammer Club, the United States Geological Survey, and the chairman and members of the local committee, who have made our attendance at this thirty-sixth annual meeting of the Society in the highest degree happy and profitable.

W. H. TWENHOFEL.
L. G. WESTGATE.

President White then announced that the business, the scientific sessions, and other activities of the annual meeting of 1923 had been completed, and on motion of L. G. Westgate, seconded by T. Wayland Vaughan, the thirty-sixth annual meeting adjourned at 12.55 o'clock.

CHARLES P. BERKEY,
Secretary.

CONSTITUTION, BY-LAWS, AND PUBLICATION RULES

REFERENCE TO ADOPTION AND CHANGES

The provisional Constitution under which the Society was organized was approved August 15, 1888, and adopted December 27, 1888 (see Bulletin, volume 1, pages 7-8). These rules were elaborated and the revised Constitution and By-Laws were adopted December 27, 1889 (volume 1, pages 536, 571-578).

Several changes have been made in these rules, which are on record in the Bulletin as follows: Changes in the Constitution: December, 1894, volume 6, page 432; December, 1897, volume 9, page 400; December, 1909, volume 21, page 19. Changes in the By-Laws: December, 1891, volume 3, page 470; December, 1893, volume 5, pages 553-554; December, 1894, volume 6, page 432; December, 1903, volume 14, page 535; December, 1909, volume 21, page 19; December, 1920, volume 32, page 13.

CONSTITUTION

ARTICLE I

NAME

This Society shall be known as THE GEOLOGICAL SOCIETY OF AMERICA.

ARTICLE II

OBJECT

The object of this Society shall be the promotion of the Science of Geology in North America.

ARTICLE III

MEMBERSHIP

The Society shall be composed of Fellows, Correspondents, and Patrons.

1. Fellows shall be persons who are engaged in geological work or in teaching geology.

Fellows admitted without election under the provisional Constitution shall be designated as Original Fellows on all lists or catalogues of the Society.

2. Correspondents shall be persons distinguished for their attainments in Geological Science and not resident in North America.

3. Patrons shall be persons who have bestowed important favors upon the Society.

4. Fellows alone shall be entitled to vote or hold office in the Society.

ARTICLE IV

OFFICERS

1. The officers of the Society shall consist of a President, a First Vice-President, a Second Vice-President, and one Vice-President to represent each of the

societies affiliated with this Society, a Secretary, a Treasurer, an Editor, and six Councilors.

These officers, together with the Presidents for the next preceding three years, shall constitute an Executive Committee, which shall be called the Council.

2. The President shall discharge the usual duties of a presiding officer at all meetings of the Society and of the Council. He shall take cognizance of the acts of the Society and of its officers, and cause the provisions of the Constitution and By-Laws to be faithfully carried into effect.

3. The First Vice-President shall assume the duties of President in case of the absence or disability of the latter. The Second Vice-President shall assume the duties of President in case of the absence or disability of both the President and First Vice-President. The Third Vice-President shall assume the duties of President in case of the absence or disability of the President and the First and Second Vice-Presidents.

4. The Secretary shall keep the records of the proceedings of the Society, and a complete list of the Fellows, with the dates of their election and disconnection with the Society. He shall also be the secretary of the Council.

The Secretary shall cooperate with the President in attention to the ordinary affairs of the Society. He shall attend to the preparation, printing and mailing of circulars, blanks and notifications of elections and meetings. He shall superintend other printing ordered by the Society or by the President, and shall have charge of its distribution, under the direction of the Council.

The Secretary, unless other provision be made, shall also act as Editor of the publications of the Society, and as Librarian and Custodian of the property.

5. The Treasurer shall have the custody of all funds of the Society. He shall keep account of receipts and disbursements in detail, and this shall be audited as hereinafter provided.

6. The Editor shall supervise all matters connected with the publication of the transactions of the Society under the direction of the Council.

7. The Council is clothed with executive authority and with the legislative powers of the Society in the intervals between its meetings; but no extraordinary act of the Council shall remain in force beyond the next following stated meeting without ratification by the Society. The Council shall have control of the publications of the Society, under provisions of the By-Laws and of resolutions from time to time adopted. They shall receive nominations for Fellows, and, on approval by them, shall submit such nomination to the Society for action. They shall have power to fill vacancies *ad interim* in any of the offices of the Society.

8. *Terms of office.*—The President and Vice-Presidents shall be elected annually, and shall not be eligible to re-election more than once until after an interval of three years after retiring from office.

The Secretary, Treasurer, and Editor shall be eligible to re-election without limitation.

The term of office of the Councilors shall be three years; and these officers shall be so grouped that two shall be elected and two retire each year. Councilors retired shall not be re-eligible till after the expiration of a year.

ARTICLE V

VOTING AND ELECTIONS

1. All elections shall be by ballot. To elect a Fellow, Correspondent or Patron, or impose any special tax, shall require the assent of nine-tenths of all Fellows voting.

2. Voting by letter may be allowed.

3. *Election of Fellows.*—Nominations for fellowship may be made by two Fellows according to a form to be provided by the Council. One of these Fellows must be personally acquainted with the nominee and his qualifications for membership. The Council will submit the nominations received by them, if approved, to a vote of the Society in the manner provided in the By-Laws. The result may be announced at any stated meeting; after which notice shall be sent out to Fellows elect.

4. *Election of officers.*—Nominations for office shall be made by the Council. The nominations shall be submitted to a vote of the Society in the same manner as nominations for fellowship. The results shall be announced at the Annual Meeting; and the officers thus elected shall enter upon duty at the adjournment of the meeting.

ARTICLE VI

MEETINGS

1. The Society shall hold at least one stated meeting a year, in the winter season. The date and place of the Winter Meeting shall be fixed by the Council, and announced each year within three months after the adjournment of the preceding Winter Meeting. The program of each meeting shall be determined by the Council, and announced beforehand, in its general features. The details of the daily sessions shall also be arranged by the Council.

2. The Winter Meeting shall be regarded as the Annual Meeting. At this, elections of officers shall be declared, and the officers elect shall enter upon duty at the adjournment of the meeting.

3. Special meetings may be called by the Council, and must be called upon the written request of twenty Fellows.

4. Stated meetings of the Council shall be held coincidently with the stated meetings of the Society. Special meetings may be called by the President at such times as he may deem necessary.

5. *Quorum.*—At meetings of the Society a majority of those registered in attendance shall constitute a quorum. Five shall constitute a quorum of the Council.

ARTICLE VII

PUBLICATION

The serial publications of the Society shall be under the immediate control of the Council.

ARTICLE VIII

SECTIONS

Any group of Fellows representing a particular branch of geology may, with consent of the Council, organize as a section of the Society with separate con-

stitution and by-laws, provided that nothing in such constitution and by-laws conflict with the Constitution and By-Laws of the Geological Society of America, in letter or spirit, and provided that such constitution and by-laws and all amendments thereto shall have been approved by the Council.

Article IX

Amendments

1. This Constitution may be amended at any annual meeting by a three-fourths vote of all the Fellows, provided that the proposed amendment shall have been submitted in print to all Fellows at least three months previous to the meeting.

2. By-laws may be made or amended by a majority vote of the Fellows present and voting at any annual meeting, provided that printed notice of the proposed amendment or by-law shall have been given to all Fellows at least three months before the meeting.

BY-LAWS

Chapter I

Of Membership

1. No person shall be accepted as a Fellow unless he pay his initiation fee, and the dues for the year, within three months after notification of his election. The initiation fee shall be ten (10) dollars and the annual dues ten (10) dollars, the latter payable on or before the annual meeting in advance; but a single prepayment of one hundred fifty (150) dollars shall be accepted as commutation for life. A Fellow in good standing, however, who has paid annual dues for not less than fifteen (15) years may commute further dues and become a Life Fellow by making a single payment of one hundred (100) dollars.

2. The sums paid in commutation of dues shall be covered into the Publication Fund.

3. An arrearage in payment of annual dues shall deprive a Fellow of the privilege of taking part in the management of the Society and of receiving the publications of the Society. An arrearage continuing over two (2) years shall be construed as notification of withdrawal.

4. Any person eligible under Article III of the Constitution may be elected Patron upon the payment of one thousand (1,000) dollars to the Publication Fund of the Society.

Chapter II

Of Officials

1. The President shall countersign, if he approves, all duly authorized accounts and orders drawn on the Treasurer for the disbursement of money.

2. The Secretary, until otherwise ordered by the Society, shall perform the duties of Editor, Librarian, and Custodian of the property of the Society.

3. The Society may elect an Assistant Secretary.

4. The Treasurer shall give bonds, with two good sureties approved by the Council, in the sum of five thousand dollars, for the faithful and honest per-

formance of his duties and the safe-keeping of the funds of the Society. He may deposit the funds in bank at his discretion, but shall not invest them without authority of the Council. His accounts shall be balanced as on the thirtieth day of November of each year.

5. In the selection of Councilors the various sections of North America shall be represented as far as practicable.

6. The minutes of the proceedings of the Council shall be subject to call by the Society.

7. The Council may transact its business by correspondence during the intervals between its stated meetings; but affirmative action by a majority of the Council shall be necessary in order to make action by correspondence valid.

CHAPTER III

OF ELECTION OF MEMBERS

1. Nominations for fellowship may be proposed at any time on blanks to be supplied by the Secretary.

2. The *form* for the nomination of Fellows shall be as follows:

In accordance with his desire, we respectfully nominate for Fellow of the Geological Society of America:

Full name; degrees; address; occupation; branch of Geology now engaged in, work already done and publications made.

(Signed by at least two Fellows.)

The form when filled is to be transmitted to the Secretary.

3. The Secretary will bring all nominations before the Council, and the Council will signify its approval or disapproval of each.

4. At least a month before one of the stated meetings of the Society the Secretary will mail a printed list of all approved nominees to each Fellow, accompanied by such information as may be necessary for intelligent voting; but an informal list of the candidates shall be sent to each Fellow at least two weeks prior to distribution of the ballots.

5. The Fellows receiving the list will signify their approval or disapproval of each nominee, and return the lists to the Secretary.

6. At the next stated meeting of the Council the Secretary will present the lists and the Council will canvass the returns.

7. The Council, by unanimous vote of the members in attendance, may still exercise the power of rejection of any nominee whom new information shows to be unsuitable for fellowship.

8. At the next stated meeting of the Society the Council shall declare the results.

9. Correspondents and Patrons shall be nominated by the Council, and shall be elected in the same manner as Fellows.

CHAPTER IV

OF ELECTION OF OFFICERS

1. The Council shall prepare a list of nominations for the several offices, which list will constitute the regular ticket. The ticket must be approved by

a majority of the entire Council. The nominee for President shall not be a member of the Council. The nominee for Third Vice-President shall be the nominee for the presidency of the Paleontological Society, which has been organized as a section under Article VIII of the Constitution. The nominee for the Vice-President representing an affiliated society shall be from the joint fellowship by vote of the affiliated society concerned, subject to confirmation by the Council of the Geological Society of America.

2. The list shall be mailed to the Fellows, for their information, at least nine months before the Annual Meeting. Any five Fellows may forward to the Secretary other nominations for any or all offices. All such nominations reaching the Secretary at least 40 days before the Annual Meeting shall be printed, together with the names of the nominators, as special tickets. The regular and special tickets shall then be mailed to the Fellows at least 25 days before the Annual Meeting.

3. The Fellows will send their ballots to the Secretary in double envelopes, the outer envelope bearing the voter's name. At the Winter Meeting of the Council, the Secretary will bring the returns of ballots before the Council for canvass, and during the Winter Meeting of the Society the Council shall declare the result.

4. In case a majority of all the ballots shall not have been cast for any candidate for any office, the Society shall by ballot at such Winter Meeting proceed to make an election for such office from the two candidates having the highest number of votes.

CHAPTER V

OF FINANCIAL METHODS

1. No pecuniary obligation shall be contracted without express sanction of the Society or the Council. But it is to be understood that all ordinary, incidental, and running expenses have the permanent sanction of the Society, without special action.

2. The creditor of the Society must present to the Treasurer a fully itemized bill, certified by the official ordering it, and approved by the President. The Treasurer shall then pay the amount out of any funds not otherwise appropriated, and the receipted bill shall be held as his voucher.

3. At each annual meeting, the President shall call upon the Society to choose two Fellows, not members of the Council, to whom shall be referred the books of the Treasurer, duly posted and balanced to the close of November thirtieth, as specified in the By-Laws, Chapter II, clause 4. The Auditors shall examine the accounts and vouchers of the Treasurer, and any member or members of the Council may be present during the examination. The report of the Auditors shall be rendered to the Society before the adjournment of the meeting, and the Society shall take appropriate action.

CHAPTER VI

OF PUBLICATIONS

1. The publications are in charge of the Council and under its control.

2. One copy of each publication shall be sent to each Fellow, Correspondent, and Patron, and each author shall receive forty (40) copies of his memoir.

CHAPTER VII

OF THE PUBLICATION FUND

1. The Publication Fund shall consist of donations made in aid of publication, and of the sums paid in commutation of dues, according to the By-Laws, Chapter I, clause 2.

2. Donors to this fund, not Fellows of the Society, in the sum of two hundred dollars, shall be entitled, without charge, to the publications subsequently appearing.

CHAPTER VIII

OF ORDER OF BUSINESS

1. The Order of Business at Winter Meetings shall be as follows:
   (1) Call to order by the presiding officer.
   (2) Introductory ceremonies.
   (3) Report of the Council (including report of the officers).
   (4) Appointment of the Auditing Committee.
   (5) Declaration of the vote for officers, and election by the meeting in case of failure to elect by the Society through transmitted ballots.
   (6) Declaration of the vote for Fellows.
   (7) Deferred business.
   (8) New business.
   (9) Announcements.
   (10) Necrology.
   (11) Reading of scientific papers.

2. At an adjourned session the order shall be resumed at the place reached on the previous adjournment, but new business will be in order before the reading of scientific papers.

3. At the Summer Meeting the items of business under numbers (3), (4), (5), (10) shall be omitted.

4. At any Special Meeting the order of business shall be numbers (1), (2), (3), (9), followed by the special business for which the meeting was called.

Publication Rules of the Geological Society of America

(Adopted by the Council April 21, 1891; Revised April 30, 1894, May, 1904, and February 5, 1910)

General Provisions

Section 1. The Council shall annually appoint from their own number a Publication Committee, consisting of the Secretary, the Treasurer, the Editor, and two others, whose duties shall be to determine the disposition of matter offered for publication, except as provided in section 12; to determine the expediency, in view of the financial condition of the Society, of publishing any matter accepted on its merits; to exercise general oversight of the matter and manner of publication; to determine the share of the cost of publication (including illustrations) to be borne by the author when it becomes necessary to divide cost between the Society and the author; to adjudicate any questions relating to publication that may be raised from time to time by the Editor or by the Fellows of the Society; and in general to act for the Council in all matters pertaining to publication. (Cons., Art. IV, 7; Art. VII; By-Laws, chap. VI.)

2. The duties of the Editor are to receive material offered for publication; to examine and submit it, with estimates of cost, to the Publication Committee; to publish all material accepted by the Council or Publication Committee; to revise proofs in connection with authors; to prepare lists of contents and general indexes; to audit bills for printing and illustrating; and to perform all other duties connected with publication not assigned to other officers. (Cons., Art. IV, 6; Rules, Sec. 16.)

3. The duties of the Secretary include the preparation of a record of the proceedings of each meeting of the Society in form for publication, and the custody, distribution, sale, exchange or other authorized disposition of the publications. (Cons., Art. IV, 4; By-Laws, chap. II, 2.)

4. Special committees may be appointed by the Council or the Publication Committee to examine and report on any matter offered for publication. (Rules, Sec. 11.)

The Bulletin

Title and general character

5. The Society shall publish a serial record of its work entitled "Bulletin of the Geological Society of America."

6. The Bulletin shall be published in quarterly parts, consecutively paged for each volume. The parts shall be suitably designated and each shall bear a title setting forth the contents and authorship, the seal and imprint of the Society and the date of publication.

7. The closing quarterly part of each volume shall contain an index, paged consecutively with the body of the volume; and it shall be accompanied by a volume title-page and lists of contents and illustrations, together with lists of

the publications of the Society and such other matter as the Publication Committee may deem necessary, all arranged under Roman pagination.

MATTER OF THE BULLETIN

8. The matter published in the Bulletin shall comprise (1) communications presented at meetings by title or otherwise; (2) communications or memoirs not presented before the Society; (3) abstracts of papers read before the Society, prepared or revised for publication by authors; (4) reports of discussions held before the Society, prepared or revised for publication by authors; (5) proceedings of the meetings of the Society prepared by the Secretary; (6) plates, maps, and other illustrations necessary for the proper understanding of communications; (7) lists of Officers and Fellows, Constitution, By-Laws, resolutions of permanent character, rules relating to procedure, to publication, and to other matters, etcetera, and (8) indexes, title-pages, and lists of contents for each volume.

9. Abstracts, reports of discussion, or other matter purporting to emanate from any author shall not be published unless prepared or revised by the author.

10. Manuscript designed for publication in the Bulletin must be complete as to copy for text and illustration, except by special arrangement between the author and the Council or Publication Committee; it must be perfectly legible (preferably typewritten) and preceded by a table of contents (section 15). The cost of necessary revision of copy or reconstruction of illustrations shall be assessed on the author.

11. The Editor shall examine matter designated for publication, and shall prepare an itemized estimate of the cost of publication and convey the whole to the Publication Committee. The Publication Committee shall then scrutinize the communication with reference, first, to relevancy; second, to scientific value; third, to literary character, and, fourth, to cost of publication, including revision. For advice with reference to the relevancy, scientific value, and literary character of any communication the Publication Committee may refer it to a special committee of their own number or of the Society at large or may call to their aid from outside one or more experts. Questions of disagreement between the Editor and authors shall be referred to the Publication Committee and appeal may be taken to the Council.

12. Communications from non-fellows shall be published only by specific authority from the Council.

13. Communications from Fellows not presented at regular meetings of the Society shall be published only upon unanimous vote of the Publication Committee, except by specific authority from the Council.

14. Matter offered for publication becomes thereby the property of the Society, and shall not be published elsewhere prior to publication in the Bulletin, except by consent of the Publication Committee.

DETAILS OF THE BULLETIN

15. The matter of each memoir shall be classified by subjects, and the classification suitably indicated by subtitles; and a list of contents shall be arranged; and such memoir may, at the option of the Publication Committee, contain an alphabetical index, provided the author prepare and pay for it.

16. Proofs of text and illustrations shall be submitted to authors whenever practicable; but printing shall not be delayed by reason of absence or incapacity of authors more than one week beyond the time required for transmission by mail. Complete proofs of the proceedings of meetings shall be sent to the Secretary, and proofs of papers and abstracts contained therein and exceeding one-half page in length shall be sent also to authors.

17. The cost of proof corrections in excess of ten per cent on the cost of printing may be charged to authors.

18. Unless the author of a memoir objects thereto, the discussion upon his communication shall be printed at the end thereof, with a suitable reference in the list of contents. In case the author objects to this arrangement, the discussion shall be printed in the closing number of the volume.

19. The author of each memoir occupying four pages or more of text in the body of the Bulletin shall receive 40 "separates" without charge, and may order through the Editor any edition of exactly similar separates at an advance of ten per cent on the cost of paper, presswork and binding; and no author's separates of such memoirs shall be issued except in this regular form.

20. Authors of papers, abstracts, or discussions less than four printed pages in length may order, through the Editor, at an advance of ten per cent on the cost of paper, presswork, binding and necessary composition, any number of extra copies, provided they bear the original pagination and a printed reference to the serial and volume from which they are extracted.

21. The Editor shall keep a record of all publications issued wholly or in part under the auspices of the Society, whether they be author's editions of memoirs, author's extracts from proceedings, or any other matter printed from type originally composed for the Bulletin.

DIRECTIONS TO PRINTER

22. Each memoir of the Bulletin shall begin under its proper title, on an odd-numbered page bearing at its head the title of the serial, the volume number, the part number, the limiting pages, the plates, and the date of publication, together with a list of contents. Each memoir shall be accompanied by the illustrations pertaining to it, the plates numbered consecutively for the volume.

23. The author's separates of each memoir shall be enclosed in a cover bearing at the head of its title-page the title of the serial, the volume number, the limiting pages, and the numbers of the contained plates; in its upper-central part a title indicating the contents and authorship; in its lower-central part the seal of the Society; and at the bottom the imprint of the Society. (See also sections 19 and 20.)

24. The bottom of each signature and each initial page will bear a signature mark giving an abbreviated title of the serial, the volume, and the year; and every page (except volume title-page) shall be numbered, the initial and subtitle pages in parentheses at bottom.

25. The page-head titles shall be: on even-numbered pages, name of author and catch title of paper; on odd-numbered pages, catch title to contents of page.

26. The date of publication of each brochure shall be the day upon which the last form is locked and put on the press.

27. The type used in printing the Bulletin shall be as follows: For memoirs, body, 10 point, 2-point leads; extracts, 8 point, 2-point leads; footnotes, 6 point, 2-point leads; titles, 10-point caps, with small caps for author's name; subtitles, 10-point caps and small caps, 6-point italic caps, etcetera, as far as practicable; for designation of cuts, 6-point caps and italics, and for legends, 6 point, Roman, 2-point leads; for lists of contents of brochures, 8 point, 2-point leads, a new line to an entry, running indentation; for volumes, the same, except names of authors in small caps; for indexes, 6 point, solid, double column, leaders, catch words in small caps, with spaces between initial letters. For serial titles, on initial pages, 8-point block caps, with corresponding small caps for volume designation, etcetera; on covers the same, except for page heads 10-point caps; for serial designation, 10 point; for brochure designation, 12-point caps; special title and author's name, etcetera, 10-point and 8-point caps; no frame on cover. No change in type shall be made to adjust matter to pages.

28. Volumes, plates, and cuts in text shall be numbered in Arabic; Roman numeration shall be used only in signature marks, and in paging the lists of contents, etcetera, arranged for binding at the beginning of the volume.

29. Imprimatur of Editor, on volume title-page; imprimatur of Council and Publication Committee, on obverse of volume title-page; imprimatur of Secretary, on initial pages and covers of brochures of proceedings. Printer's card, in fine type on obverse of title-page.

30. The paper shall be for body of volume, 70-pound toned paper, folding to 16 x 25 centimeters; for plates, good quality plate paper, smooth-surfaced, white, cut to 6½ x 10 inches for single plates; for covers, smooth-surfaced, fine quality 70-pound light-buff manila paper.

31. The sheets of the brochures shall be stitched with thread; single page plates shall be stitched with the sheets of the brochure; folding plates may be either gummed or stitched (mounted on stubs if necessary); covers shall be gummed.

EDITION, DISTRIBUTION, AND PRICE

32. The regular edition shall be 850 copies in the regular quarterly form and 50 copies separately in covers of each memoir occupying four pages or more of text. Each author of a memoir occupying not less than four pages of text shall receive 40 copies of his memoir gratis. If two or more authors contribute to a memoir brochure of four pages or more in length, the edition shall be enlarged so as to give each author 40 copies. (By-Laws, chap. VI, 2.)

33. The undistributed residue of separates shall be held for sale.

34. The Bulletin shall be sent free to Fellows of the Society not in arrears for dues, and also to exchanging institutions. (By-Laws, chap. I, 3.)

35. The price of the Bulletin shall be as follows: To Fellows, libraries, and institutions, and to individuals not residing in North America, $9 per volume; to individuals residing in North America and who are not Fellows, $10. The price of each brochure shall be a multiple of five cents, and shall be, to Fellows, one cent per page plus three cents per plate, and to the public an advance of fifty per cent on the price to Fellows. The prices of the separate brochures and of the quarterly parts may be found in the front of each volume.

Register of the Washington Meeting, 1923

FELLOWS

Frank D. Adams
L. H. Adams
William C. Alden
E. T. Allen
Harold L. Alling
H. M. Ami
George H. Ashley
Wallace W. Atwood
H. Foster Bain
M. B. Baker
Sydney Ball
Joseph A. Bancroft
Florence Bascom
R. S. Bassler
Edson S. Bastin
Alan M. Bateman
Charles P. Berkey
Edward W. Berry
N. L. Bowen
William Bowie
J. H. Bownocker
Alfred H. Brooks
Charles W. Brown
A. F. Buddington
H. A. Buehler
E. F. Burchard
Charles Butts
F. C. Calkins
M. R. Campbell
Charles Camsell
Stephen R. Capps
E. C. Case
George H. Chadwick
A. P. Coleman
A. J. Collier
C. Wythe Cooke
Whitman Cross
J. A. Cushman
Nelson C. Dale
Reginald A. Daly
N. H. Darton
A. L. Day
J. S. Diller
E. T. Dumble
Carl O. Dunbar
C. N. Fenner
Henry G. Ferguson
August F. Foerste
Wilbur G. Foye
J. J. Galloway
Julia Gardner
J. W. Gidley
Albert W. Giles
L. C. Glenn
Marcus I. Goldman
L. C. Graton
Herbert E. Gregory
G. D. Harris
Chris. A. Hartnagel
Oliver P. Hay
K. C. Heald
Frank L. Hess
D. F. Hewett
William H. Hobbs
R. J. Holden
Oliver B. Hopkins
W. O. Hotchkiss
E. O. Hovey
Walter F. Hunt
E. C. Jacobs
Bertrand L. Johnson
Anna I. Jonas
Frank J. Katz
George F. Kay
Arthur Keith
James F. Kemp

EDWIN KIRK
ADOLPH KNOPF
ELEANORA BLISS KNOPF
F. H. KNOWLTON
EDWARD H. KRAUS
HENRY B. KUMMEL
GEORGE F. KUNZ
ALFRED C. LANE
ESPER S. LARSEN
ANDREW C. LAWSON
W. T. LEE
M. M. LEIGHTON
C. K. LEITH
J. VOLNEY LEWIS
WALDEMAR LINDGREN
HOMER P. LITTLE
GEORGE D. LOUDERBACK
G. F. LOUGHLIN
RICHARD S. LULL
GEORGE C. MARTIN
LAWRENCE MARTIN
K. F. MATHER
EDWARD B. MATHEWS
F. E. MATTHES
W. D. MATTHEW
O. E. MEINZER
W. C. MENDENHALL
JOHN C. MERRIAM
GEORGE P. MERRILL
H. E. MERWIN
W. G. MILLER
WILLIAM J. MILLER
FRED. H. MOFFIT
RAYMOND C. MOORE
WILBUR A. NELSON
SIDNEY PAIGE
W. A. PARKS
R. A. F. PENROSE, JR.
W. C. PHALEN
ALEXANDER H. PHILLIPS
W. ARMSTRONG PRICE
LOUIS M. PRINDLE
T. T. QUIRKE
CHESTER A. REEDS
J. B. REESIDE
HARRY FIELDING REID
WILLIAM NORTH RICE
RALPH W. RICHARDS
CHARLES H. RICHARDSON
G. B. RICHARDSON
H. RIES
A. F. ROGERS
T. E. SAVAGE
ROBERT W. SAYLES
W. T. SHALLER
F. C. SHRADER
CHARLES SCHUCHERT
E. W. SHAW
C. E. SIEBENTHAL
WILLIAM J. SINCLAIR
JOSEPH T. SINGEWALD, JR.
GEORGE OTIS SMITH
PHILIP S. SMITH
ROBERT B. SOSMAN
ARTHUR C. SPENCER
J. E. SPURR
T. W. STANTON
EDWARD STEIDTMANN
R. W. STONE
GEORGE W. STOSE
CHARLES K. SWARTZ
MIGNON TALBOT
MALCOLM R. THORPE
W. H. TWENHOFEL
J. A. UDDEN
E. O. ULRICH
J. B. UMPLEBY
FRANK R. VAN HORN
T. WAYLAND VAUGHAN
T. L. WALKER
CHARLES W. WARREN
CHESTER W. WASHBURNE

H. S. Washington
T. L. Watson
R. C. Wells
Lewis R. Westgate
Edgar T. Wherry
David White
I. C. White
Herbert P. Whitlock
Frank A. Wilder
Wendell P. Woodring
Fred. E. Wright

FELLOWS-ELECT

Ferdinand Julius Fohs
John Beaver Mertie, Jr.

In addition to the foregoing, there were registered at the meeting 187 members of affiliated societies and visitors.

Lists of former Officers and Meetings, with Dates

By recommendation of the Council, a complete list of past officers, with the dates of their service, is now printed for the first time in the Proceedings.

PRESIDENTS

1889. James Hall
1890. James D. Dana
1891. Alexander Winchell
1892. G. K. Gilbert
1893. J. William Dawson
1894. T. C. Chamberlin
1895. N. S. Shaler
1896. Joseph Le Conte
1897. Edward Orton
1898. J. J. Stevenson
1899. B. K. Emerson
1900. G. M. Dawson
1901. C. D. Walcott
1902. N. H. Winchell
1903. S. F. Emmons
1904. J. C. Branner
1905. Raphael Pumpelly
1906. I. C. Russell
1907. C. R. Van Hise
1908. Samuel Calvin
1909. Grove K. Gilbert
1910. Arnold Hague
1911. William M. Davis
1912. H. L. Fairchild
1913. Eugene A. Smith
1914. George F. Becker
1915. Arthur P. Coleman
1916. John M. Clarke
1917. Frank D. Adams
1918. Whitman Cross
1919. J. C. Merriam
1920. I. C. White
1921. James F. Kemp
1922. Charles Schuchert
1923. David White

VICE-PRESIDENTS

(Not including *ex-officio* Vice-Presidents representing the affiliated societies)

1889.	James D. Dana	Alexander Winchell
1890.	J. S. Newberry	A. Winchell
1891.	G. K. Gilbert	T. C. Chamberlin
1892.	J. W. Dawson	T. C. Chamberlin
1893.	T. C. Chamberlin	J. J. Stevenson
1894.	N. S. Shaler	G. H. Williams

1895.	Joseph Le Conte	Charles H. Hitchcock
1896.	Charles H. Hitchcock	Edward Orton
1897.	J. J. Stevenson	B. K. Emerson
1898.	B. K. Emerson	G. M. Dawson
1899.	G. M. Dawson	C. D. Walcott
1900.	C. D. Walcott	N. H. Winchell
1901.	N. H. Winchell	S. F. Emmons
1902.	S. F. Emmons	J. C. Branner
1903.	Arnold Hague	H. S. Williams
1904.	H. S. Williams	Samuel Calvin
1905.	Samuel Calvin	W. M. Davis
1906.	W. M. Davis	E. A. Smith
1907.	J. S. Diller	A. P. Coleman
1908.	George F. Becker	A. C. Lawson
1909.	Frank D. Adams	John M. Clarke
1910.	Charles Schuchert	A. P. Low
1911.	William North Rice	
1912.	Israel C. White	
1913.	James F. Kemp	R. D. Salisbury
1914.	Waldemar Lindgren	Horace B. Patton
1915.	L. V. Pirsson	H. P. Cushing
1916.	J. P. Iddings	H. F. Reid
1917.	A. C. Lawson	W. D. Matthew
1918.	Bailey Willis	Frank Leverett
1919.	R. A. F. Penrose, Jr.	Herbert E. Gregory
1920.	George P. Merrill	W. G. Miller
1921.	J. B. Woodworth	Arthur Keith
1922.	Henry S. Washington	Robert T. Hill
1923.	W. H. Hobbs	W. H. Emmons

TREASURERS

1889–1891.	H. S. Williams
1892–1906.	I. C. White
1907–1917.	W. B. Clark
1917–	E. B. Mathews

SECRETARIES

1889–1890.	John J. Stevenson.
1891–1906.	H. L. Fairchild
1907–1922.	E. O. Hovey
1923–	Charles P. Berkey

EDITORS

1890–1892.	W J McGee
1893–	J. Stanley-Brown

COUNCILORS

1889.	J. W. Powell	J. S. Newberry
1890.	J. W. Powell	G. M. Dawson C. H. Hitchcock
1891.	George M. Dawson	J. C. Branner
1892.	N. H. Winchell	H. S. Williams
1893.	E. A. Smith	C. D. Walcott
1894.	F. D. Adams	I. C. Russell
1895.	R. W. Ells	C. R. Van Hise

1896.	B. K. Emerson	J. M. Stafford
1897.	J. S. Diller	W. B. Scott
1898.	Robert Bell	M. E. Wadsworth
1899.	W. M. Davis	Joseph A. Holmes
1900.	W. B. Clark	A. C. Lawson
1901.	Samuel Calvin	Arthur P. Coleman
1902.	C. W. Hayes	J. P. Iddings
1903.	R. D. Salisbury	J. E. Wolff
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1906.	A. C. Lane	David White
1907.	H. E. Gregory	H. F. Reid
1908.	H. P. Cushing	H. B. Patton
1909.	G. O. Smith	H. S. Washington
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1913.	Whitman Cross	W. G. Miller
1914.	R. A. F. Penrose, Jr.	W. W. Atwood
1915.	Charles K. Leith	Thomas L. Watson
1916.	Frank B. Taylor	Charles P. Berkey
1917.	Arthur L. Day	William H. Emmons
1918.	Joseph Barrell	R. A. Daly
1919.	William S. Bayley	Eugene W. Shaw
1920.	T. W. Vaughan	George F. Kay
1921.	L. C. Graton	G. D. Louderback
1922.	E. S. Bastin	L. G. Westgate
1923.	E. O. Hovey	A. H. Brooks

ANNUAL AND SEMI-ANNUAL MEETING PLACES OF THE GEOLOGICAL SOCIETY OF AMERICA

1888. Ithaca, New York.
1889. Toronto, Canada, August.
New York City, December.
1890. Indianapolis, Indiana, August.
Washington, D. C., December.
1891. Washington, D. C., August.
Columbus, Ohio, December.
1892. Rochester, New York, August.
Ottawa, Canada, December.
1893. Madison, Wisconsin, August.
Boston, Massachusetts, December.
1894. Brooklyn, New York, August.
Baltimore, Maryland, December.
1895. Springfield, Massachusetts, August.
Philadelphia, Pennsylvania, December.
1896. Buffalo, New York, August.
Washington, D. C., December.

1897. Detroit, Michigan, August.
Montreal, Canada, December.
1898. Boston, Massachusetts, August.
New York City, December.
1899. Columbus, Ohio, August.
Washington, D. C., December.
1900. New York City, June.
Albany, New York, December.
1901. Denver, Colorado, August.
Rochester, New York, December.
1902. Pittsburgh, Pennsylvania, July.
Washington, D. C., December.
1903. Saint Louis, Missouri, December.
1904. Philadelphia, Pennsylvania, December.
1905. Ottawa, Canada, December.
1906. New York City, December.
1907. Albuquerque, New Mexico, December.
1908. Baltimore, Maryland, December.
1909. Cambridge and Boston, Massachusetts, December.
1910. Pittsburgh, Pennsylvania, December.
1911. Washington, D. C., December.
1912. New Haven, Connecticut, December.
1913. Princeton, New Jersey, December.
1914. Philadelphia, Pennsylvania, December.
1915. Stanford University, California, August.
Washington, D. C., December.
1916. Albany, New York, December.
1917. Saint Louis, Missouri, December.
1918. Baltimore, Maryland, December.
1919. Boston, Massachusetts, December.
1920. Chicago, Illinois, December.
1921. Amherst, Massachusetts, December.
1922. Ann Arbor, Michigan, December.
1923. Washington, D. C., December.

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

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WALDEMAR LINDGREN, Cambridge, Mass.

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JOHAN A. UDDEN, Austin, Texas
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(Term expires 1926)

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WILLIAM H. TWENHOFEL, Madison, Wis.

MEMBERSHIP, 1924

CORRESPONDENTS

BARROIS, CHARLES, Lille, France. Dec., 1909.
BRÖGGER, W. C., Christiania, Norway. Dec., 1909.
CAPELLINI, GIOVANNI, Bologna, Italy. Dec., 1910.
DAVID, SIR THOMAS W. EDGEWORTH, Sydney, New South Wales. Dec., 1923.
DE GEER, BARON GERHARD, Stockholm, Sweden. Dec., 1910.
DE MARGERIE, EMMANUEL, Strassburg, Alsace, France. Dec., 1921.
GEIKIE, SIR ARCHIBALD, Haslemere, England. Dec., 1909.
HEIM, ALBERT, Zurich, Switzerland. Dec., 1909.
KAYSER, EMANUEL, Marburg, Germany. Dec., 1909.
KILIAN, W., Grenoble, France. Dec., 1912.
KOTO, BUNJIRO, Tokyo, Japan. Dec., 1923.
LACROIX, FRANCOIS ANTOINE ALFRED, Paris, France. Dec., 1923.
MOLENGRAAFF, GUSTAAF ADOLF FREDERIK, Delft, Holland. Dec., 1923.
SEDERHOLM, JAKOB JOHANNES, Helsingfors, Finland. Dec., 1923.
TEALL, J. J. H., London, England. Dec., 1912.
TIETZE, EMIL, Vienna, Austria. Dec., 1910.
WOODWARD, ARTHUR SMITH, London, England. Dec., 1923.

FELLOWS

* Indicates Original Fellows (see article III of Constitution)

ABBE, CLEVELAND, JR., College of the City of New York, New York, N. Y. August, 1899.
ADAMS, FRANK DAWSON, McGill University, Montreal, Canada. Dec., 1889.
ADAMS, GEORGE I., University of Alabama, Tuscaloosa, Ala. Dec., 1902.
ADAMS, LEASON H., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ADKINS, WALTER S., Apartado 150, Tampico, Tamaulipas, Mexico. Dec., 1921.
ALCOCK, F. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
ALDEN, WILLIAM C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
ALDRICH, TRUMAN H., 1026 Glen Iris Ave., Birmingham, Ala. May, 1889.
ALLAN, JOHN A., University of Alberta, Edmonton, Alberta, Canada. Dec., 1914.
ALLEN, EUGENE T., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ALLEN, R. C., 1202 Hanna Bldg., Cleveland, Ohio. Dec., 1911.
ALLING, H. L., University of Rochester, Rochester, N. Y. Dec., 1920.
AMI, HENRY M., Victoria Museum, Room 105, Ottawa, Canada. Dec., 1889.
ANDERSON, FRANK M., State Mining Bureau, 2604 Ætna St., Berkeley, Calif. Dec., 1902.
ANDERSON, ROBERT V., Menlo Park, Calif. Dec., 1911.
ANDREWS, E. C., Geol. Surv. of N. S. W., Sydney, N. S. Wales. Dec., 1920.
ARNOLD, RALPH, 639 South Spring St., Los Angeles, Calif. Dec., 1904.
ASHLEY, GEORGE HALL, State Capitol, Harrisburg, Pa. August, 1895.
ATWOOD, WALLACE WALTER, Clark University, Worcester, Mass. Dec., 1909.
BAGG, RUFUS MATHER, JR., 7 Brokaw Place, Appleton, Wis. Dec., 1896.
BAIN, H. FOSTER, 1430 33d St. N. W., Washington, D. C. Dec., 1895.
BAKER, MANLEY BENSON, School of Mining, Kingston, Ontario. Dec., 1911.

BALDWIN, S. PRENTISS, 11025 East Blvd., Cleveland, Ohio. August, 1895.
BALL, SYDNEY H., 42 Broadway, New York City. Dec., 1905.
BANCROFT, JOSEPH A., McGill University, Montreal, Canada. Dec., 1914.
BARBOUR, ERWIN HINCKLEY, University of Nebraska, Lincoln, Neb. Dec., 1896.
BARRETT, LESLIE PARK, Geol. Surv. of Michigan, Lansing, Mich. Dec., 1923.
BARTON, DONALD C., Amerada Petr. Corp., Houston, Texas. Dec., 1921.
BARTON, GEORGE H., Boston Soc. of Nat. History, Boston, Mass. Aug., 1890.
BARTSCH, PAUL, U. S. National Museum, Washington, D. C. Dec., 1917.
BASCOM, FLORENCE, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
BASSLER, RAY SMITH, U. S. National Museum, Washington, D. C. Dec., 1906.
BASTIN, EDSON S., University of Chicago, Chicago, Ill. Dec., 1909.
BATEMAN, ALAN MARA, Yale University, New Haven, Conn. Dec., 1916.
BAUER, CLYDE MAX, 114 Yellowstone Ave., Billings, Mont. Dec., 1923.
BAYLEY, WILLIAM S., University of Illinois, Urbana, Ill. Dec., 1888.
BEEDE, JOSHUA W., 200 S. Seneca Ave., Bartlesville, Okla. Dec., 1902.
BELL, WALTER A., Victoria Memorial Museum, Ottawa, Canada. Dec., 1923.
BENSON, W. N., University of Otago, Dunedin, New Zealand. Dec., 1919.
BERKEY, CHARLES P., Columbia University, New York, N. Y. August, 1901.
BERRY, EDWARD WILBER, Johns Hopkins University, Baltimore, Md. Dec., 1909.
BEYER, SAMUEL WALKER, Iowa Agricultural College, Ames, Iowa. Dec., 1896.
BILLINGSLEY, PAUL, 605 Pioneer Bldg., Seattle, Wash. Dec., 1922.
BLACKWELDER, ELIOT, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1908.
BOUTWELL, JOHN M., Natl. Copper Bank, Salt Lake City, Utah. Dec., 1905.
BOWEN, CHARLES F., c/o Standard Oil Co., 26 Broadway, New York City. Dec., 1916.
BOWEN, N. L., Geophysical Laboratory, Washington, D. C. Dec., 1917.
BOWIE, WILLIAM, U. S. Coast and Geodetic Survey, Washington, D. C. Dec., 1919.
BOWNOCKER, JOHN ADAMS, Ohio State University, Columbus, Ohio. Dec., 1904.
BRANSON, EDWIN BAYER, University of Missouri, Columbia, Mo. Dec., 1911.
BRETZ, J. H., University of Chicago, Chicago, Ill. Dec., 1917.
BRIGHAM, ALBERT PERRY, Colgate University, Hamilton, N. Y. Dec., 1893.
BROCK, REGINALD W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.
BRODERICK, T. MONTEITH, Calumet and Hecla Mining Co., Calumet, Mich. Dec., 1921.
BROKAW, A. D., 157 Maplewood Ave., Maplewood, N. J. Dec., 1920.
BROOKS, ALFRED HULSE, U. S. Geological Surv., Washington, D. C. Aug., 1899.
BROWN, BARNUM, American Museum of Natural History, New York, N. Y. Dec., 1910.
BROWN, CHARLES WILSON, Brown University, Providence, R. I. Dec., 1908.
BROWN, JOHN STAFFORD, Box 709, Rolla, Mo. Dec., 1922.
BROWN, THOMAS CLACHAR, Laurel Bank Farm, Fitchburg, Mass. Dec., 1915.
BRUCE, E. L., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
BRYAN, KIRK, U. S. Geological Survey, Washington, D. C. Dec., 1922.
BUCHER, W. H., University of Cincinnati, Cincinnati, Ohio. Dec., 1920.
BUDDINGTON, A. F., 124 Pyne Hall, Princeton, N. J. Dec., 1919.
BUEHLER, HENRY ANDREW, Rolla, Mo. Dec., 1909.
BUECHARD, E. F., U. S. Geological Survey, Washington, D. C. Dec., 1920.

BURLING, LANCASTER D., Whitehall Petr. Corp., 53 Parliament St., Westminster, S. W. I., London, England. Dec., 1917.
BURWASH, EDWARD M. J., 556 Bathurst St., Toronto, Canada. Dec., 1916.
BUTLER, BERT S., Box 277, Calumet, Mich. Dec., 1912.
BUTLER, G. MONTAGUE, College of Mines, Tucson, Arizona. Dec., 1911.
BUTTS, CHARLES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
BUWALDA, J. P., University of California, Berkeley, Calif. Dec., 1920.
CADY, G. H., Fayetteville, Ark. Dec., 1920.
CALHOUN, FRED HARVEY HALL, Clemson College, S. C. Dec., 1909.
CALKINS, FRANK C., U. S. Geological Survey, Washington, D. C. Dec., 1914.
CAMPBELL, HENRY D., Washington and Lee Univ., Lexington, Va. May, 1889.
CAMPBELL, MARIUS R., U. S. Geological Survey, Washington, D. C. Aug., 1892.
CAMSELL, CHARLES, Department of Mines, Ottawa, Canada. Dec., 1914.
CAPPS, STEPHEN R., JR., U. S. Geological Surv., Washington, D. C. Dec., 1911.
CARMAN, J. ERNEST, Ohio State University, Columbus, Ohio. Dec., 1917.
CARNEY, FRANK, Box 309, Eldorado, Kans. Dec., 1908.
CASE, ERMINE C., University of Michigan, Ann Arbor, Mich. Dec., 1901.
CHADWICK, GEORGE H., 305 Maverick Bldg., San Antonio, Texas. Dec., 1911.
CHAMBERLIN, ROLLIN T., University of Chicago, Chicago, Ill. Dec., 1913.
*CHAMBERLIN, T. C., Hyde Park Hotel, Hyde Park Blvd. and Harper Ave., Chicago, Ill.
CLAPP, CHARLES H., State University, Missoula, Mont. Dec., 1914.
CLAPP, FREDERICK G., 30 Church St., New York City. Dec., 1905.
CLARK, BRUCE L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
CLARK, F. R., 723 Petroleum Bldg., Tulsa, Okla. Dec., 1919.
CLARK, W. O., Pahala, Kau, Hawaii. Dec., 1920.
CLARKE, JOHN MASON, Education Bldg., Albany, N. Y. Dec., 1897.
CLELAND, HERDMAN F., Williams College, Williamstown, Mass. Dec., 1905.
CLEMENTS, J. MORGAN, 20 Broad St., New York City. Dec., 1894.
COBB, COLLIER, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
COLEMAN, ARTHUR P., Toronto University, Toronto, Canada. Dec., 1896.
COLLIE, GEORGE L., Beloit College, Beloit, Wis. Dec., 1897.
COLLINS, WILLIAM H., Geological Survey, Ottawa, Canada. Dec., 1921.
COLLIER, ARTHUR J., U. S. Geological Survey, Washington, D. C. June, 1902.
CONDIT, D. DALE, c/o Whitehall Petr. Corp., Ltd., 83 The Mall, Lahore, India. Dec., 1916.
COOK, CHARLES W., University of Michigan, Ann Arbor, Mich. Dec., 1915.
COOKE, C. WYTHE, U. S. Geological Survey, Washington, D. C. Dec., 1918.
COSTE, EUGENE, 622 Dallas County-State Bank Bldg., Dallas, Texas. Dec., 1906.
CRAWFORD, RALPH DIXON, 1050 Tenth St., Boulder, Colo. Dec., 1916.
CROOK, ALJA R., State Museum of Natural History, Springfield, Ill. Dec., 1898.
*CROSBY, WILLIAM O., Massachusetts Institute of Technology, Boston, Mass.
CROSS, WHITMAN, 101 East Kirke St., Chevy Chase, Md. May, 1889.
CULVER, GARRY E., 310 Center Ave., Stevens Point, Wis. Dec., 1891.
CUMINGS, EDGAR R., Indiana University, Bloomington, Ind. August, 1901.
CUSHMAN, J. A., Sharon, Mass. Dec., 1919.
DAKE, C. L., Missouri School of Mines, Rolla, Mo. Dec., 1920.
DALE, N. C., Hamilton College, Clinton, N. Y. Dec., 1920.
DALY, REGINALD A., Harvard University, Cambridge, Mass. Dec., 1905.

DANA, EDWARD SALISBURY, Yale University, New Haven, Conn. Dec., 1908.
*DARTON, NELSON H., U. S. Geological Survey, Washington, D. C.
DAVIS, E. F., 417 E. Randolph St., Glendale, Calif. Dec., 1920.
*DAVIS, WILLIAM M., 31 Hawthorne St., Cambridge, Mass.
DAY, ARTHUR LOUIS, Geophysical Laboratory, Washington, D. C. Dec., 1909.
DAY, DAVID T., 1333 F St. N. W., Washington, D. C. August, 1891.
DEAN, BASHFORD, Riverdale-on-Hudson, New York, N. Y. Dec., 1910.
DE GOLYER, E. L., 65 Broadway, New York City. Dec., 1918.
DEUSSEN, ALEXANDER. 504 Stewart Bldg., Houston, Texas. Dec., 1916.
DE WOLF, FRANK WILBRIDGE, Humphreys Oil Co., Great Southern Life Bldg., Dallas, Texas. Dec., 1909.
DICKERSON, ROY E., Masonic Temple Bldg., Manila, P. I. Dec., 1918.
*DILLER, JOSEPH S., U. S. Geological Survey, Washington, D. C.
D'INVILLIERS, EDWARD V., 121 North Broad St., Philadelphia, Pa. Dec., 1888.
DODGE, RICHARD E., Storrs, Conn. August, 1897.
DOLMAGE, VICTOR, 510 Pacific Bldg., Vancouver, B. C. Dec., 1922.
DRAKE, NOAH FIELDS, Fayetteville, Ark. Dec., 1898.
DRESSER, JOHN A., 701 Eastern Townships Bank Bldg., Montreal, Canada. Dec., 1906.
*DUMBLE, EDWIN T., 316 Pacific Bldg., Houston, Texas.
DUNBAR, C. O., Yale University, New Haven, Conn. Dec., 1920.
EAKLE, ARTHUR S., University of California, Berkeley, Calif. Dec., 1899.
ECKEL, EDWIN C., 1503 Decatur St. N. W., Washington, D. C. Dec., 1905.
EMERY, WILSON B., Casper, Wyoming. Dec., 1919.
*EMERSON, BENJAMIN K., Amherst, Mass.
EMMONS, WILLIAM H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.
*FAIRCHILD, HERMAN L., University of Rochester, Rochester, N. Y.
FARRINGTON, OLIVER C., Field Museum of Natural History, Chicago, Ill. Dec., 1895.
FATH, A. E., Vacuum Oil Co., 61 Broadway, New York, N. Y. Dec., 1920.
FENNEMAN, NEVIN M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
FENNER, CLARENCE N., Geophysical Laboratory, Washington, D. C. Dec., 1911.
FERGUSON, H. G., U. S. Geological Survey, Washington, D. C. Dec., 1920.
FISHER, CASSIUS ASA, 705 First Nat'l Bank Bldg., Denver, Colo. Dec., 1908.
FOERSTE, AUGUST F., 129 Wroe Ave., Dayton, Ohio. Dec., 1899.
FOHS, FERDINALD JULIUS, 60 Broadway, New York, N. Y. Dec., 1923.
FORD, WILLIAM E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.
FOYE, W. G., Wesleyan University, Middletown, Conn. Dec., 1919.
FULLER, MYRON L., 60 Main St., Brockton, Mass. Dec., 1898.
GALLOWAY, J. J., Columbia University, New York, N. Y. Dec., 1920.
GALPIN, SIDNEY L., 630 Park Ave., Ames, Iowa. Dec., 1917.
GANE, HENRY STEWART, Rural Del. No. 1, Santa Barbara, Calif. Dec., 1896.
GARDNER, JAMES H., 626 Kennedy Bldg., Tulsa, Okla. Dec., 1911.
GARDNER, JULIA A., U. S. Geological Survey, Washington, D. C. Dec., 1920.
GEORGE, RUSSELL D., University of Colorado, Boulder, Colo. Dec., 1906.
GIDLEY, JAMES WILLIAM, U. S. Nat'l Museum, Washington, D. C. Dec., 1922.
GILES, ALBERT W., University of Virginia, University, Va. Dec., 1921.
GILL, ADAM CAPEN, Cornell University, Ithaca, N. Y. Dec., 1888.
GLENN, L. C., 2111 Garland Ave., Nashville, Tenn. June, 1900.

GOLDMAN, MARCUS ISAAC, U. S. Geol. Survey, Washington, D. C. Dec., 1916.
GOLDRING, WINIFRED, New York State Museum, Albany, N. Y. Dec., 1921.
GOLDTHWAIT, JAMES WALTER, Dartmouth College, Hanover, N. H. Dec., 1909.
GORDON, CHARLES H., University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
GORDON, CLARENCE E., Massachusetts Agricultural College, Amherst, Mass. Dec., 1913.
GOULD, CHARLES N., 1218 Colcord Bldg., Oklahoma City, Okla. Dec., 1904.
GRABAU, AMADEUS W., Government University, Peking, China. Dec., 1898.
GRANGER, WALTER, American Museum of Natural History, New York, N. Y. Dec., 1911.
GRANT, ULYSSES SHERMAN, Northwestern Univ., Evanston, Ill. Dec., 1890.
GRASTY, JOHN SHARSHALL, Box 458, Charlottesville, Va. Dec., 1911.
GRATON, LOUIS C., Foxcroft House, Cambridge, 38, Mass. Dec., 1913.
GREGORY, HERBERT E., Yale University, New Haven, Conn. August, 1901.
GREENE, FRANK COOK, 1434 S. Cincinnati Ave., Tulsa, Okla. Dec., 1917.
GRIMSLEY, GEORGE P., 16 York Court, Baltimore, Md. August, 1895.
GROUT, FRANK F., University of Minnesota, Minneapolis, Minn. Dec., 1918.
GRUNER, JOHN W., University of Minnesota, Minneapolis, Minn. Dec., 1923.
GURLEY, WILLIAM F. E. R., University of Chicago, Chicago, Ill. Dec., 1914.
HALBERSTADT, BAIRD, Pottsville, Pa. Dec., 1909.
HANCE, J. H., 708 W. Washington Blvd., Urbana, Ill. Dec., 1920.
HANCOCK, E. T., Strada-Stavropoleos 6, Bucharest, Rumania. Dec., 1919.
HARDER, E. C., 1111 Harrison Bldg., Philadelphia, Pa. Dec., 1918.
HARES, C. J., The Ohio Oil Co., Casper, Wyo. Dec., 1920.
HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. Dec., 1903.
HARRISON, JOHN BURCHMORE, Georgetown, British Guiana. June, 1902.
HARTNAGEL, CHRIS A., Education Bldg., Albany, N. Y. Dec., 1913.
HASTINGS, JOHN B., 520 Cohengo Ave., Los Angeles, Calif. May, 1889.
*HAWORTH, ERASMUS, University of Kansas, Lawrence, Kans.
HAY, OLIVER P., Carnegie Institution, Washington, D. C. Dec., 1921.
HAYES, ALBERT O., c/o Carr Bros., Inc., 65 Broadway, N. Y. City. Dec., 1919.
HEALD, K. C., U. S. Geological Survey, Washington, D. C. Dec., 1920.
HENNEN, RAY V., 1701 Benedum-Trees Bldg., Pittsburgh, Pa. Dec., 1914.
HERSHEY, OSCAR H., Crocker Bldg., San Francisco, Calif. Dec., 1909.
HESS, FRANK L., U. S. Geological Survey, Washington, D. C. Dec., 1921.
HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
HICE, RICHARD R., Beaver, Pa. Dec., 1903.
HILL, J. M., U. S. Geological Survey, Washington, D. C. Dec., 1920.
*HILL, ROBERT T., 1239 N. Central Ave., Glendale, Calif.
HINDS, HENRY, 1153 Laurel Ave., St. Paul, Minn. Dec., 1912.
HINTZE, FERDINAND FRIIS, 580 Corona St., Denver, Colo. Dec., 1917.
HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.
HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.
HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. Dec., 1910.
HOLLICK, ARTHUR, N. Y. Botanical Garden, New York, N. Y. August, 1898.
HOPKINS, O. B., Internat. Petr. Co., Ltd., 56 Church St., Toronto, Canada. Dec., 1919.
HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. Dec., 1894.

HOTCHKISS, WILLIAM OTIS, State Geological Surv., Madison, Wis. Dec., 1911.
*HOVEY, EDMUND OTIS, American Museum of Natural History, New York, N. Y.
HOWE, ERNEST, Litchfield, Conn. Dec., 1903.
HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. Dec., 1914.
HUDSON, GEORGE H., Plattsburg Normal School, Plattsburg, N. Y. Dec., 1917.
HUME, GEORGE S., Geological Survey of Canada, Ottawa, Canada. Dec., 1923.
HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. Dec., 1914.
HUNTINGTON, ELLSWORTH, Yale University, New Haven, Conn. Dec., 1906.
HUSSAKOF, LOUIS, 1537 50th St., Brooklyn, N. Y. Dec., 1910.
HYDE, J. E., Western Reserve University, Cleveland, Ohio. Dec., 1916.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.
JACOBS, ELBRIDGE C., University of Vermont, Burlington, Vt. Dec., 1921.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. Dec., 1904.
JEFFREY, EDWARD C., Harvard University, Cambridge, Mass. Dec., 1914.
JENKINS, OLAF P., State College, Pullman, Wash. Dec., 1921.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. Dec., 1908.
JOHNSON, B. L., U. S. Geological Survey, Washington, D. C. Dec., 1919.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.
JOHNSON, ROSWELL H., University of Pittsburgh, Pittsburgh, Pa. Dec., 1918.
JONAS, ANNA I., Room 4230, U. S. Geological Survey, Washington, D. C. Dec., 1922.
KATZ, FRANK JAMES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
*KEMP, JAMES F., Columbia University, New York, N. Y.
KENNEDY, WILLIAM, 2909 S. Jennings Ave., Fort Worth, Texas. Dec., 1923.
KEW, W. S. W., 901 S. Norton Ave., Los Angeles, Calif. Dec., 1920.
KEYES, CHARLES ROLLIN, 944 Fifth St., Des Moines, Iowa. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
KIRK, CHARLES T., Box 1592, Tulsa, Okla. Dec., 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KNIGHT, CYRIL WORKMAN, Nipissing Mining Co., Ltd., Cobalt, Ontario, Canada. Dec., 1911.
KNOPF, ADOLPH, Yale Station New Haven, Conn. Dec., 1911.
KNOPF, ELEANORA BLISS, 105 East Rock Road, New Haven, Conn. Dec., 1919.
KNOWLTON, FRANK H., U. S. National Museum, Washington, D. C. May, 1889.
KRAUS, EDWARD HENRY, Univ. of Michigan, Ann Arbor, Mich. June, 1902.
KUMMEL, HENRY B., Trenton, N. J. Dec., 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LAHEE, FREDERIC H. Dec., 1917.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. Dec., 1908.
LANE, ALFRED C., Tufts College, Mass. Dec., 1889.
LARSEN, ESPER S., JR., Geol. Mus., Harvard Univ., Cambridge, Mass. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Calif. May, 1889.
LEE, WILLIS THOMAS, U. S. Geological Survey, Washington, D. C. Dec., 1903.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. Dec., 1914.

LEIGHTON, MORRIS M., University of Illinois, Urbana, Ill. Dec., 1921.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. Dec., 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEWIS, JOSEPH VOLNEY, Rutgers College, New Brunswick, N. J. Dec., 1906.
LIBBEY, WILLIAM, Princeton University, Princeton, N. J. August, 1899.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.
LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. Dec., 1913.
LITTLE, HOMER P., Clark University, Worcester, Mass. Dec., 1918.
LLOYD, E. R., First National Bank Bldg., Denver, Colo. Dec., 1919.
LOGAN, WILLIAM N., Indiana University, Bloomington, Ind. Dec., 1917.
LONGWELL, CHESTER R., Yale University, New Haven, Conn. Dec., 1923.
LOOMIS, FREDERICK BREWSTER, Amherst College, Amherst, Mass. Dec., 1909.
LOUDERBACK, GEORGE D., University of California, Berkeley, Calif. June, 1902.
LOUGHLIN, GERALD F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
LOW, ALBERT P., 154 McLaren St., Ottawa, Canada. Dec., 1905.
LULL, RICHARD SWANN, Yale University, New Haven, Conn. Dec., 1909.
LUPTON, CHARLES T., 611 17th St., Denver, Colo. Dec., 1916.
MCCALLIE, SAMUEL WASHINGTON, Atlanta, Ga. Dec., 1909.
MCCASKEY, HIRAM D., Central Point, Oregon. Dec., 1904.
MCCONNELL, RICHARD G., Rideau Club, Ottawa, Canada. May, 1889.
MCCOY, ALEX. W., Bartlesville, Okla. Dec., 1922.
MACDONALD, DONALD F., 45 Nassau St., New York City. Dec., 1915.
MACFARLANE, JAMES RIEMAN, Woodland Road, Pittsburgh, Pa. August, 1891.
MCINNES, WILLIAM, Geological and Natural History Survey of Canada. Ottawa, Canada. May, 1889.
MACKAY, BERTRAM R., Geological Survey, Ottawa, Canada. Dec., 1922.
MCKELLAR, PETER, Fort William, Ontario, Canada. August, 1890.
MCLAUGHLIN, DONALD H., 53 Parker Ave., San Francisco, Calif. Dec., 1922.
MANSFIELD, GEORGE R., 2067 Park Rd. N. W., Washington, D. C. Dec., 1909.
MARBUT, CURTIS F., Bureau of Soils, Washington, D. C. August, 1897.
MARSTERS, VERNON F., 123 Railway Exchange Bldg., Kansas City, Mo. Aug., 1892.
MARTIN, GEORGE C., U. S. Geological Survey, Washington, D. C. June, 1902.
MARTIN, LAWRENCE, Dept. of State, Room 381, Washington, D. C. Dec., 1909.
MATHER, KIRTLEY F., 1775 Massachusetts Ave., Cambridge, Mass. Dec., 1918.
MATHEWS, EDWARD B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
MATSON, GEORGE C., 408 Cosden Bldg., Tulsa, Okla. Dec., 1918.
MATTHES, FRANCOIS E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
MATTHEW, W. D., American Museum of Natural History, New York, N. Y. Dec., 1903.
MAURY, CARLOTTA J., Hastings-on-Hudson, N. Y. Dec., 1920.
MAYNARD, THOMAS POOLE, 1622 D. Hurt Bldg., Atlanta, Ga. Dec., 1914.
MEAD, WARREN JUDSON, University of Wisconsin, Madison, Wis. Dec., 1916.
MEHL, MAURICE G., University of Missouri, Columbia, Mo. Dec., 1922.

MEINZER, OSCAR E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MENDENHALL, WALTER C., U. S. Geol. Survey, Washington, D. C. June, 1902.
MERRIAM, JOHN C., Carnegie Institution, Washington, D. C. August, 1895.
MERRILL, GEORGE P., U. S. National Museum, Washington, D. C. Dec., 1888.
MERTIE, JOHN BEAVER, JR., 112 Park Ave., Takoma Park, D. C. Dec., 1923.
MERWIN, HERBERT E., Geophysical Laboratory, Washington, D. C. Dec., 1914.
MILLER, ARTHUR M., State University of Kentucky, Lexington, Ky. Dec., 1897.
MILLER, BENJAMIN L., Lehigh University, Bethlehem, Pa. Dec., 1904.
MILLER, WILLET G., Toronto, Canada. Dec., 1902.
MILLER, WILLIAM JOHN, Smith College, Northampton, Mass. Dec., 1909.
MISER, HUGH D., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MOFFIT, FRED HOWARD, U. S. Geological Survey, Washington, D. C. Dec., 1912.
MOORE, ELWOOD S., University of Toronto, Toronto, Canada. Dec., 1911.
MOORE, RAYMOND C., University of Kansas, Lawrence, Kans. Dec., 1921.
MOOK, CHARLES C., Metuchen, N. J. Dec., 1922.
MUNN, MALCOLM JOHN, Clinton Bldg., Tulsa, Okla. Dec., 1909.
*NASON, FRANK L., West Haven, Conn.
NELSON, W. A., Tennessee Geological Survey, Nashville, Tenn. Dec., 1920.
NEWLAND, DAVID HALE, Albany, N. Y. Dec., 1906.
NEWSOM, JOHN F., Leland Stanford Jr. University, Stanford University, Calif. Dec., 1899.
NOBLE, LEVI F., Valyermo, Calif. Dec., 1916.
NORTON, WILLIAM H., Cornell College, Mount Vernon, Iowa. Dec., 1895.
NORWOOD, CHARLES J., State University, Lexington, Ky. August, 1894.
O'CONNELL, MARJORIE, 2026 S. Jefferson Ave., St. Louis, Mo. Dec., 1919.
OGILVIE, IDA HELEN, Barnard College, Columbia University, New York, N. Y. Dec., 1906.
O'HARA, CLEOPHAS C., South Dakota School of Mines, Rapid City, S. Dak. Dec., 1904.
OHERN, DANIEL WEBSTER, 515 W. 14th St., Oklahoma City, Okla. Dec., 1911.
O'NEILL, J. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
OSBORN, HENRY F., American Museum of Natural History, New York, N. Y. August, 1894.
OVERBECK, ROBERT M., 834 East Ocean Blvd., Long Beach, Calif. Dec., 1921.
PACK, ROBERT W., Box 790, Beaumont, Texas. Dec., 1916.
PAIGE, SIDNEY, U. S. Geological Survey, Washington, D. C. Dec., 1911.
PALACHE, CHARLES, Harvard University, Cambridge, Mass. August, 1897.
PARKS, WILLIAM A., University of Toronto, Toronto, Canada. Dec., 1906.
*PATTON, HORACE B., 3111 West 36th Ave., Denver, Colo.
PECK, FREDERICK B., Lafayette College, Easton, Pa. August, 1901.
PENROSE, RICHARD A. F., JR., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.
PERKINS, GEORGE H., University of Vermont, Burlington, Vt. June, 1902.
PERRY, JOSEPH H., 276 Highland St., Worcester, Mass. Dec., 1888.
PHALEN, WILLIAM C., 61 Broadway, New York, N. Y. Dec., 1912.
PHILLIPS, ALEXANDER H., Princeton University, Princeton, N. J. Dec., 1914.
POGUE, JOSEPH E., 42 West 12th St., New York City. Dec., 1911.
POWERS, SIDNEY, Amerada Petr. Corp., Tulsa, Okla. Dec., 1920.
PRATT, JOSEPH H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
PRATT, W. E., Humble Oil and Refining Co., Houston, Texas. Dec., 1920.

PRICE, WILLIAM A., 502 Stanley Ave., Clarksburg, W. Va. Dec., 1916.
PRINDLE, LOUIS M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
PROUTY, WILLIAM F., Univ. of North Carolina, Chapel Hill, N. C. Dec., 1911.
QUIRKE, TERENCE T., University of Illinois, Urbana, Ill. Dec., 1921.
RANSOME, FREDERICK L., University Station, Tucson, Ariz. August, 1895.
RAYMOND, PERCY EDWARD, Museum of Comparative Zoology, Cambridge, Mass. Dec., 1907.
REBER, LOUIS E., Box 1096, Jerome, Ariz. Dec., 1923.
REEDS, CHESTER A., American Museum of Natural History, New York, N. Y. Dec., 1913.
REESIDE, JOHN B., JR., U. S. Geological Survey, Hyattsville, Md. Dec., 1921.
REGER, DAVID B., Box 816, Morgantown, W. Va. Dec., 1918.
REID, HARRY FIELDING, Johns Hopkins University, Baltimore, Md. Dec., 1892.
REINECKE, LEOPOLD, P. O. Box 2682, Johannesburg, Transvaal, South Africa. Dec., 1916.
RICE, WILLIAM NORTH, Wesleyan University, Middletown, Conn. Aug., 1890.
RICH, JOHN LYON, Box 3, Ottawa, Kans. Dec., 1912.
RICHARDS, R. W., U. S. Geological Survey, Washington, D. C. Dec., 1920.
RICHARDSON, CHARLES H., Syracuse University, Syracuse, N. Y. Dec., 1899.
RICHARDSON, GEORGE B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.
RIES, HEINRICH, Cornell University, Ithaca, N. Y. Dec., 1893.
RIGGS, ELMER S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.
ROBINSON, HENRY HOLLISTER, Yale University, Hopkins Hall, New Haven, Conn. Dec., 1916.
RODDY, H. J., State Normal School, Millersville, Pa. Dec., 1919.
ROGERS, AUSTIN F., Stanford University, Calif. Dec., 1918.
ROSE, BRUCE, Department of Geology, Queens University, Kingston, Ontario, Canada. Dec., 1916.
RUEDEMANN, RUDOLF, Albany, N. Y. Dec., 1905.
RUTLEDGE, JOHN JOSEPH, State Bureau of Mines, 22 Light St., Baltimore, Md. Dec., 1911.
SALES, RENO H., Anaconda Copper Mining Co., Butte, Mont. Dec., 1916.
SAYLES, ROBERT WILCOX, Harvard University, Chestnut Hill, Mass. Dec., 1917.
SARDESON, FREDERICK W., Univ. of Minnesota, Minneapolis, Minn. Dec., 1892.
SAVAGE, THOMAS EDMUND, University of Illinois, Urbana, Ill. Dec., 1907.
SCHALLER, WALDEMAR T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.
SCHOFIELD, S. J., University of British Columbia, Vancouver, B. C. Dec., 1918.
SCHRADER, FRANK C., U. S. Geological Survey, Washington, D. C. Aug., 1901.
SCHUCHERT, CHARLES, Yale University, New Haven, Conn. August, 1895.
SCHULTZ, ALFRED R., Hudson, Wis. Dec., 1912.
SCHWARTZ, GEORGE M., Univ. of Minnesota, Minneapolis, Minn. Dec., 1923.
SCOTT, IRVING D., University of Michigan, Ann Arbor, Mich. Dec., 1923.
SCOTT, WILLIAM B., Princeton University, Princeton, N. J. August, 1892.
SEAMAN, ARTHUR E., Michigan College of Mines, Houghton, Mich. Dec., 1904.
SELLARDS, ELIAS H., University of Texas, Austin, Texas. Dec., 1905.
SEMMES, DOUGLAS R., Apartado postal, 150, Tampico, Tamaulipas, Mexico. Dec., 1921.
SHALER, MILLARD K., 66 Rue Des Colonies, Brussels, Belgium. Dec., 1914.
SHANNON, CHARLES W., Bureau of Geology, Norman, Okla. Dec., 1918.

SHATTUCK, GEORGE BURBANK, 24 E. Mt. Vernon Place, Baltimore, Md. Aug., 1899.
SHAW, EUGENE W., 170 Broadway, New York, N. Y. Dec., 1912.
SHEDD, SOLON, State College of Washington, Pullman, Wash. Dec., 1904.
SHEPARD, EDWARD M., 1403 Benton Ave., Springfield, Mo. August, 1901.
SHIMEK, BOHUMIL, University of Iowa, Iowa City, Iowa. Dec., 1904.
SHIMER, HERVEY WOODBURN, Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1910.
SHULER, E. W., South Methodist University, Dallas, Texas. Dec., 1920.
SIEBENTHAL, CLAUDE E., U. S. Geol. Survey, Washington, D. C. Dec., 1912.
*SIMONDS, FREDERICK W., University of Texas, Austin, Texas.
SIMPSON, HOWARD E., University of North Dakota, Grand Forks, N. Dak. Dec., 1923.
SINCLAIR, WILLIAM JOHN, Princeton University, Princeton, N. J. Dec., 1906.
SINGEWALD, JOSEPH T., Johns Hopkins University, Baltimore, Md. Dec., 1911.
SLOAN, EARLE, Charleston, S. C. Dec., 1908.
SMITH, BURNETT, Syracuse University, Syracuse, N. Y. Dec., 1911.
SMITH, CARL, Box 1136, Tulsa, Okla. Dec., 1912.
*SMITH, EUGENE A., University of Alabama, University, Ala.
SMITH, GEORGE OTIS, U. S. Geological Survey, Washington, D. C. Aug., 1897.
SMITH, PHILIP S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
SMITH, RICHARD A., Biological Survey of Michigan, Lansing, Mich. Dec., 1921.
SMITH, STANLEY, University of Bristol, Bristol, England. Dec., 1922.
SMITH, WARREN DU PRÉ, University of Oregon, Eugene, Ore. Dec., 1909.
SMITH, W. S. TANGIER, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.
*SMOCK, JOHN C., Hudson, N. Y.
SMYTH, CHARLES H., JR., Princeton University, Princeton, N. J. Aug., 1892.
SMYTH, HENRY L., Harvard University, Cambridge, Mass. August, 1894.
SOMERS, R. E., Oil and Gas Bldg., University of Pittsburgh, Pittsburgh, Pa. Dec., 1919.
SOPER, EDGAR K., 120 Broadway, New York City, Room 3101. Dec., 1918.
SOSMAN, R. B., Geophysical Laboratory, Washington, D. C. Dec., 1920.
SPEIGHT, ROBERT, Canterbury College, Christ Church, New Zealand. Dec., 1916.
SPENCER, ARTHUR COE, U. S. Geological Survey, Washington, D. C. Dec., 1896.
SPRINGER, FRANK, U. S. National Museum, Washington, D. C. Dec., 1911.
SPURR, JOSIAH E., c/o Engineering and Mining Journal, 10th Ave. and 36th St., New York, N. Y. Dec., 1894.
STANLEY-BROWN, JOSEPH, 26 Exchange Place, New York, N. Y. August, 1892.
STANTON, TIMOTHY W., U. S. Nat'l Museum, Washington, D. C. August, 1891.
STAUFFER, CLINTON R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.
STEBINGER, EUGENE, JR., Room 322, 26 Broadway, New York, N. Y. Dec., 1916.
STEIDTMANN, EDWARD, 13 White St., Lexington, Va. Dec., 1916.
STEPHENSON, LLOYD W., U. S. Geol. Survey, Washington, D. C. Dec., 1911.
*STEPHENSON, JOHN J., 215 West 101st St., New York, N. Y.
STOLLER, JAMES HOUGH, Union College, Schenectady, N. Y. Dec., 1917.
STONE, RALPH WALTER, State Geological Survey, Harrisburg, Pa. Dec., 1912.
STOSE, GEORGE WILLIS, U. S. Geological Survey, Washington, D. C. Dec., 1908.
STOUT, WILBER, Geological Survey of Ohio, Columbus, Ohio. Dec., 1918.
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md. Dec., 1908.

TABER, STEPHEN, University of South Carolina, Columbia, S. C. Dec., 1914.
TAFF, JOSEPH A., 629 Cooper St., Palo Alto, Calif. August, 1895.
TALBOT, MIGNON, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
TALMAGE, JAMES E., 47 E. So. Temple St., Salt Lake City, Utah. Dec., 1897.
TARR, WILLIAM ARTHUR, University of Missouri, Columbia, Mo. Dec., 1917.
TAYLOR, FRANK B., 420 Downing Ave., Fort Wayne, Ind. Dec., 1895.
THOMAS, ABRAM O., University of Iowa, Iowa City, Iowa. Dec., 1921.
THORPE, MALCOLM R., 1463 Yale Station, New Haven, Conn. Dec., 1923.
TILTON, J. L., Morgantown, W. Va. Dec., 1920.
TOMLINSON, CHARLES WELDON, 1610 Bixby Ave., Ardmore, Okla. Dec., 1917.
TROWBRIDGE, ARTHUR C., State Univ. of Iowa, Iowa City, Iowa. Dec., 1913.
TROXELL, EDWARD L., Yale Station, New Haven, Conn. Dec., 1923.
*TURNER, HENRY W., Mills Bldg., San Francisco, Calif.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis. Dec., 1913.
TWITCHELL, MAYVILLE W., State Geological Survey, Trenton, N. J. Dec., 1911.
TYRRELL, JOSEPH B., Confederation Life Bldg., Toronto, Canada. May, 1889.
UDDEN, JOHAN A., University of Texas, Austin, Texas. August, 1897.
UGLOW, WILLIAM L., University of British Columbia, Vancouver, B. C. Dec., 1922.
ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C. Dec., 1903.
UMPLEBY, JOSEPH B., University of Oklahoma, Norman, Okla. Dec., 1913.
*UPHAM, WARREN, Minnesota Historical Society, Saint Paul, Minn.
VAN HORN, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
VAN INGEN, GILBERT, Princeton University, Princeton, N. J. Dec., 1904.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo. Dec., 1917.
VAUGHAN, T. WAYLAND, Scripps Institution, La Jolla, Calif. August, 1896.
VEATCH, ARTHUR CLIFFORD, 7 Central Drive, Port Washington, N. Y. Dec., 1906.
VISHER, STEPHEN S., 817 E. Second St., Bloomington, Ind. Dec., 1923.
WADE, BRUCE, State Geological Survey, Nashville, Tenn. Dec., 1920.
*WALCOTT, CHARLES D., Smithsonian Institution, Washington, D. C.
WALKER, THOMAS L., University of Toronto, Toronto, Canada. Dec., 1903.
WARING, GERALD A., Margay Oil Corp., Box 2103, Tulsa, Okla. Dec., 1921.
WARREN, CHARLES H., Yale University, New Haven, Conn. Dec., 1901.
WASHBURNE, C. W., 2 Rector St., New York, N. Y. Dec., 1919.
WASHINGTON, HENRY S., Geophysical Laboratory, Washington, D. C. Aug., 1896.
WATSON, THOMAS L., University of Virginia, Charlottesville, Va. June, 1900.
WEAVER, CHARLES E., 264 Herkimer Road, Utica, N. Y. Dec., 1913.
WEED, WALTER H., Tuckahoe, N. Y. May, 1889.
WEGEMANN, CARROLL H., P. O. Box 240, Denver, Colo. Dec., 1912.
WEIDMAN, SAMUEL, 814 Monett St., Norman, Okla. Dec., 1903.
WELLER, STUART, University of Chicago, Chicago, Ill. June, 1900.
WELLS, ROGER C., U. S. Geological Survey, Washington, D. C. Dec., 1921.
WENTWORTH, CHESTER K., Bishop Museum, Honolulu, Hawaii. Dec., 1923.
WESTGATE, LEWIS G., 124 Oak Hill Ave., Delaware, Ohio. August, 1894.
WHERRY, EDGAR T., Bureau of Chemistry, Washington, D. C. Dec., 1915.
WHITE, DAVID, U. S. National Museum, Washington, D. C. May, 1889.
*WHITE, ISRAEL C., Morgantown, W. Va.

WHITLOCK, H. P., Amer. Museum of Natural History, N. Y. City. Dec., 1920.
WHITNEY, FRANCIS L., University of Texas, Austin, Texas. Dec., 1923.
WIELAND, GEORGE REBER, Yale University, New Haven, Conn. Dec., 1910.
WILDER, FRANK A., North Holston, Smyth County, Va. Dec., 1905.
*WILLIAMS, EDWARD H., JR., Woodstock, Vt.
WILLIAMS, IRA A., Oregon Bureau of Mines and Geology, 417 Oregon Bldg., Portland, Ore. Dec., 1905.
WILLIAMS, MERTON YARWOOD, Univ. of British Columbia, Vancouver, B. C. Dec., 1916.
WILLIS, BAILEY, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1889.
WILSON, ALFRED W. G., Department of Mines, Ottawa, Canada. June, 1902.
WILSON, MORLEY EVANS, Geological Survey, Ottawa, Canada. Dec., 1916.
WINCHELL, ALEXANDER N., University of Wisconsin, Madison, Wis. Aug., 1901.
*WINSLOW, ARTHUR, 131 State St., Boston, Mass.
WOLFF, JOHN E., Harvard University, Cambridge, Mass. Dec., 1889.
WOOD, HARRY OSCAR, Mt. Wilson Observatory, Pasadena, Calif. Dec., 1922.
WOODMAN, JOSEPH E., New York University, New York, N. Y. Dec., 1905.
WOODRING, WENDELL P., U. S. Geol. Survey, Washington, D. C. Dec., 1921.
WOODRUFF, E. G. Dec., 1922.
WOODWARD, ROBERT S., Carnegie Institution, Washington, D. C. May, 1889.
WOODWORTH, JAY B., Geological Museum, 38 Oxford St., Cambridge, Mass. Dec., 1895.
WRATHER, WILLIAM E., 6044 Bryan Parkway, Dallas, Texas. Dec., 1923.
WRIGHT, CHARLES WILL, 28 Vie del Parliamento, Rome, Italy. Dec., 1909.
WRIGHT, FREDERIC E., Geophysical Laboratory, Washington, D. C. Dec., 1903.

CORRESPONDENTS DECEASED

CREDNER, HERMAN. Died July 22, 1913.
MICHEL-LÉVY, A. Died September, 1911.
ROSENBUSCH, H. Died January 20, 1914.
SUESS, EDWARD. Died April 20, 1914.
TSCHERNYSCHEW, TH. Died Jan. 15, 1914.
ZIRKEL, FERDINAND. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*ASHBURNER, CHAS. A. Died Dec. 24, 1889.
BARLOW, ALFRED E. Died May 28, 1914.
BARRELL, JOSEPH. Died May 4, 1919.
BEECHER, CHARLES E. Died Feb. 14, 1904.
*BECKER, GEORGE F. Died April 20, 1919.
BELL, ROBERT. Died June 18, 1917.
BICKMORE, ALBERT S. Died Aug. 12, 1914.
BLAKE, WM. PHIPPS. Died May 21, 1910.
BOWMAN, AMOS. Died June 18, 1894.
*BRANNER, JOHN C. Died March 1, 1922.
BROWN, AMOS P. Died Oct. 9, 1917.
BUCKLEY, ERNEST R. Died Jan. 19, 1912.
CAIRNES, D. D. Died June 14, 1917.
*CALVIN, SAMUEL. Died April 17, 1911.
CARPENTER, FRANK R. Died April 1, 1910.
CASTILLO, ANTONIO DEL. Died Oct. 28, 1895.
CHAPIN, J. H. Died March 14, 1892.
CLARK, WILLIAM B. Died July 27, 1917.
*CLAYPOLE, EDWARD W. Died Aug. 17, 1901.
*COMSTOCK, THEO. B. Died July 26, 1915.
COOK, GEORGE H. Died Sept. 22, 1889.
*COPE, EDWARD D. Died April 12, 1897.
COX, GEORGE H. Died August 20, 1922.
*CUSHING, H. P. Died April 14, 1921.
*DANA, JAMES D. Died April 14, 1895.
DAVIS, CHARLES A. Died April 9, 1916.
DAWSON, GEORGE M. Died March 2, 1901.
DAWSON, SIR J. WM. Died Nov. 19, 1899.
DERBY, ORVILLE A. Died Nov. 27, 1915.
DRYSDALE, CHAS. W. Died July 10, 1917.
DUTTON, CLARENCE E. Died Jan. 4, 1912.
*DWIGHT, WM. B. Died Aug. 29, 1906.

EASTMAN, CHAS. R. Died Sept. 27, 1918.
*ELDRIDGE, GEORGE H. Died June 29, 1905.
*EMMONS, SAMUEL F. Died March 28, 1911.
FONTAINE, WM. M. Died April 30, 1913.
*FOOTE, ALBERT E. Died October 10, 1895.
*FRAZER, PERSIFOR. Died April 7, 1909.
*FULLER, HOMER T. Died Aug. 14, 1908.
*GILBERT, GROVE K. Died May 1, 1918.
GIROUX, N. J. Died November 30, 1891.
HAGUE, ARNOLD. Died May 14, 1917.
*HALL, CHRISTOPHER W. Died May10, 1911.
*HALL, JAMES. Died August 7, 1898.
HATCHER, JOHN B. Died July 3, 1904.
*HAY, ROBERT. Died December 14, 1895.
HAYES, C. WILLARD. Died Feb. 9, 1916.
*HEILPRIN, ANGELO. Died July 17, 1907.
HILGARD, EUGENE W. Died Jan. 8, 1916.
HILL, FRANK A. Died July 13, 1915.
HILLS, RICHARD C. Died Aug. 14, 1923.
*HITCHCOCK, CHAS. H. Died Nov. 7, 1919.
*HOLBROOK, LEVI. Died July 26, 1922.
*HOLMES, JOSEPH A. Died July 13, 1915.
HONEYMAN, DAVID. Died Oct. 17, 1889.
*HOWELL, EDWIN E. Died April 16, 1911.
*HOVEY, HORACE C. Died July 27, 1914.
HUNT, THOMAS S. Died Feb. 12, 1892.
*HYATT, ALPHEUS. Died Jan. 15, 1902.
IDDINGS, J. P. Died Sept. 8, 1920.
IRVING, JOHN D. Died July 26, 1918.
JACKSON, THOMAS M. Died Feb. 3, 1912.
*JAMES, JOSEPH F. Died March 29, 1897.
JULIEN, ALEXIS A. Died May 7, 1919.
KNIGHT, WILBUR C. Died July 28, 1903.
LACOE, RALPH D. Died February 5, 1901.
LAFLAMME, J. C. K. Died July 6, 1910.
LAMBE, L. M. Died March 12, 1919.
LANGTON, DANIEL W. Died June 21, 1909.
*LE CONTE, JOSEPH. Died July 6, 1901.
*LESLEY, J. PETER. Died June 2, 1903.
LOUGHRIDGE, ROBT. H. Died July 1, 1917.
MCCALLEY, HENRY. Died Nov. 20, 1904.
*MCGEE, W J. Died September 4, 1912.
MARCY, OLIVER. Died March 19, 1899.
MARSH, OTHNIEL C. Died March 18, 1899.
MELL, P. H. Died October 12, 1918.
*MERRILL, FRED. J. H. Died Nov. 29, 1916.
MILLS, JAMES E. Died July 25, 1901.
*NASON, HENRY B. Died Jan. 17, 1895.
*NEFF, PETER. Died May 11, 1903.
*NEWBERRY, JOHN S. Died Dec. 7, 1892.
NILES, WILLIAM H. Died Sept. 12, 1910.
*ORTON, EDWARD. Died October 16, 1899.
*OSBORN, AMOS O. Died March, 1911.
*OWEN, RICHARD. Died March 24, 1890.
PENFIELD, SAMUEL L. Died Aug. 14, 1906.
PENHALLOW, DAVID P. Died Oct. 20, 1910.
PIRSSON, L. V. Died Dec. 8, 1919.
*PLATT, FRANKLIN. Died July 24, 1900.
PETTEE, WILLIAM H. Died May 26, 1904.
*POWELL, JOHN W. Died Sept. 23, 1902.
*PROSSER, CHAS. S. Died Sept. 11, 1916.
*PUMPELLY, RAPHAEL. Died August, 1923.
PURDUE, A. H. Died Dec. 12, 1917.
ROGERS, G. S. Died Nov. 18, 1919.
*RUSSELL, ISRAEL C. Died May 1, 1906.
*SAFFORD, JAMES M. Died July 3, 1907.
*SALISBURY, ROLLIN D. Died Aug. 15, 1922.
*SCHAEFFER, CHARLES. Died Nov. 23, 1903.
SEELY, H. M. Died May 4, 1917.
SEÑA, J. C. DA COSTA. Died June 20, 1919.
*SHALER, NATHANIEL S. Died Apr. 10, 1906.
*SPENCER, J. W. Died October 9, 1921.
SAINT JOHN, O. H. Died July 17, 1921.
SUTTON, WILLIAM J. Died May 9, 1915.
TARR, RALPH S. Died March 21, 1912.
TIGHT, WILLIAM G. Died Jan. 15, 1910.
*TODD, JAMES E. Died October 29, 1922.
*VAN HISE, C. R. Died Nov. 19, 1918.
*VOGDES, ANTHONY W. Died Feb. 8, 1923.
WACHSMUTH, CHAS. Died Feb. 7, 1896.
WADSWORTH, M. E. Died April 21, 1921.
WESTON, THOMAS C. Died July 20, 1910.
WHITE, THEODORE G. Died July 7, 1901.
*WHITFIELD, ROBT. P. Died April 6, 1910.
*WILLIAMS, GEORGE H. Died July 12, 1894.
*WILLIAMS, J. FRANCIS. Died Nov. 9, 1891.
*WILLIAMS, H. S. Died July 31, 1918.
WILMOTT, ARTHUR B. Died May 8, 1914.
*WINCHELL, ALEX. Died Feb. 19, 1891.
*WINCHELL, H. V. Died July 28, 1923.
*WINCHELL, NEWTON H. Died May 1, 1914.
WRIGHT, ALBERT A. Died April 2, 1905.
*WRIGHT, G. F. Died April 20, 1921.
YEATES, WILLIAM S. Died Feb. 19, 1908.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 161-168 MARCH 30, 1924

PROCEEDINGS OF THE TWENTY-SECOND ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT BERKELEY, CALIFORNIA, MARCH 17, 1923.

JOHN P. BUWALDA, *Secretary*

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Session of March 17

The Cordilleran Section of the Geological Society of America held its twenty-second annual meeting at Bacon Hall, University of California, on March 17, 1923, in conjunction with the Pacific Coast Section of the Paleontological Society of America and the Le Conte Club.

ELECTION OF OFFICERS

The following officers were elected to serve during 1924:

Chairman, William S. W. Kew
Secretary, John P. Buwalda
Councilor, Eliot Blackwelder

PROGRAM OF PAPERS

The meeting was called to order at 9.50 a. m. by the Chairman of the Section, W. S. W. Kew.

The following papers were presented in the order indicated:

PLEISTOCENE FORMATION AND FAUNA FROM PEARD BAY, ALASKA

BY CHARLES E. MEEK

Read in full.

NEW EARLIEST KNOWN VERTEBRATES

BY A. J. TIEJE

(*Abstract*)

New Ordovician vertebrate remains have been discovered by T. S. Lovering and the writer 3 miles west of the mouth of Rock River Canyon, Big Horn Mountains, Wyoming. The horizon is debatably Upper Cambrian, but it is thought best to place it as Lower Middle Ordovician. The remains (chiefly scales) are tentatively classed as those of *Coelolepidæ* (genus *Theolodus?*) and of *Cephalaspidæ* (genus *Ateleaspis?*). Some fragments seem entirely new.

Presented from notes. Discussed by Messrs. Camp and Stock.

PALEONTOLOGICAL PROSPECTS IN COLOMBIA

BY F. M. ANDERSON

Presented extemporaneously and illustrated by lantern slides. Discussed by Mr. Kew.

PRELIMINARY REPORT ON A TERTIARY FLORA FROM NORTHWESTERN NEVADA

BY RALPH W. CHANEY

(*Abstract*)

The Davis Creek beds, comprising a series of tuff, sandstone, and shale, are extensively exposed in the northern part of Washoe County, Nevada, where

they underlie the Modoc lavas. In the vicinity of 49 Camp there are several ledges of white diatomaceous ash which contain leaf impressions, and silicified stumps, some of which are found frequently in position. Of fourteen species determined from leaf impressions, eight are among the more common members of the Mascall flora of the John Day Basin of Oregon, four occur in the Auriferous gravel flora at Table Mountain, California, and there is one each from the Payette of Nevada and the Florissant of Colorado. These four floras are Miocene, with the possible exception of that from Table Mountain, which, though it appears to be Miocene, is associated with Hipparion remains which may indicate the lower Pliocene age of this portion of the Auriferous Gravels. Of twelve additional species, which are doubtfully determined, nearly all are closely related to Miocene species. The Miocene age of the Davis Creek beds seems to be clearly established by this flora, which combines members of the Great Basin floras of Oregon and Idaho with those from the floras of the Auriferous Gravels and the Coast Ranges of California.

Presented from notes. Discussed by Messrs. Hanna, Louderback, Nelson, and Morse.

MINERALOGY AND PETROGRAPHY OF FOSSIL BONE

BY AUSTIN F. ROGERS

(*Abstract*)

Fossil bones consist largely of collophane, an amorphous mineral with the composition

$$3\,Ca_3(PO_4)_2 . n\,Ca(CO_3, F_2, O, SO_4) . (H_2O)\,x$$

where n varies from 1 to 2 and x is indefinite. The index of refraction of the collophane varies from 1.57 to 1.62. The frequency curve with 200 examples is a skew curve with the mode, arithmetic mean, and median near 1.605. The associated minerals include calcite, quartz, chalcedony, opal, barite, dolomite, pyrite, and rarely wavellite and datolite. The replacement of collophane by calcite is very common, but its replacement by the silica minerals is very rare. The microscopic structure of bone is retained in the fossilized state. It does not seem likely that the geological age of a fossil bone can be determined from the character of the collophane.

Presented extemporaneously and illustrated by lantern slides. Discussed by Messrs. Eakle, Tieje, Kew, Buwalda, and Blackwelder.

The Section adjourned at 12.15 for lunch.

After a short business meeting, the afternoon session was called to order by Chairman Kew at 2.15.

JURASSIC STRATIGRAPHY OF THE ALASKAN PENINSULA

BY ROY R. MORSE

(*Abstract*)

A brief statement of the results of a study of the Jurassic stratigraphy of the central Alaskan Peninsula. The succession furnishes an interesting comparison with the California Mesozoic.

Presented from notes and illustrated with aid of reflectoscope. Discussed by Messrs. Turner, Louderback, and Blackwelder.

GEOLOGICAL RECORD IN BRITISH COLUMBIA

BY STUART J. SCHOFIELD

(*Abstract*)

1. A Paleozoic and early Mesozoic basin of sedimentation extended from the old land of Cascadia eastward to the Canadian shield. Cascadia at this time was a part of the area now occupied by the Pacific Ocean, and its eastern shoreline stretched in a northwesterly direction just west of the present coastline of North America. The northern border of Cascadia extended in a westerly direction just south of the peninsula of Alaska.

2. During the Jurasside revolution, a name which may be applied to that period of mountain-building which occurred in Upper Jurassic times, three great mountain chains appeared in this basin.

(*a*) The Vancouver Island—Queen Charlotte Island range and the Coast Range of British Columbia.
(*b*) The Sierra Nevada range.
(*c*) The Selkirks and their extension northward and southward into the Bitterroot and Clearwater Mountains.

3. The Alaskides were formed during the Jurasside revolution along the northern border of Cascadia.

4. The granite batholiths which accompanied the Jurasside revolution were intruded during the Upper Jurassic times.

5. Basins of Cretaceous sedimentation occurred on both flanks of these Jurassic mountains.

6. These basins, in Canada at least, were affected by the Laramide revolution, which was accompanied by igneous intrusions.

7. It is considered that Cascadia, which persisted as a continent in the Pacific at least until the Laramide revolution, disappeared beneath the waters of the Pacific either by faulting or folding in the Tertiary period.

Read by title.

PROPOSED QUANTITATIVE AND MINERALOGICAL CLASSIFICATION OF IGNEOUS ROCKS

BY EDWIN T. HODGE

(*Abstract*)

The classification of most known igneous rocks presented on a single plane. Their variation chemically and mineralogically can be traced continuously in all directions. The rocks are classified (1) upon the total percentage of quartz, feldspar, and feldspathoids present, (2) upon the individual percentages of quartz, feldspathoids, olivine alone, olivine and feldspathoids, and metallics, and (3) upon the percentage ratio of orthoclase to the various members of the plagioclases.

The table permits rocks at present unknown but containing the above constituents to be classified. Rocks classified chemically fall into the same divisions as those classified mineralogically. The table can be simplified for

field use. The classification deals with modal minerals and not with normic minerals. The classification is in harmony with the established concepts employed by earlier and authoritative classificationists.

Presented extemporaneously. Illustrated by large chart. Discussed by Messrs. Morse, Blackwelder, Fickell, and Louderback.

UNIQUE GARNET SAND FORMING ALONG THE BEACH AT THE MOUTH OF THE SUR RIVER, MONTEREY COUNTY, CALIFORNIA

BY PARKER D. TRASK

(*Abstract*)

The sand is composed of about 70 per cent garnet, 3 per cent quartz, 3 per cent feldspar, and varying amounts of other minerals, of which magnetite is the most abundant. The minerals are derived from an area of crystalline schists and granites. The origin of the sand is similar to that of magnetitic beach sands, being due to the sorting action of wind and waves on heavy minerals. The deposit is lenticular and grades laterally into sands consisting chiefly of quartz and feldspar. If this region were to undergo dynamic metamorphism, the resulting product might be mistaken for that of contact metamorphism with the addition of new materials, especially so since the garnetiferous beds could be followed along the strike into ordinary sandstones.

Read from manuscript. Discussed by Messrs. Rogers, Louderback, F. M. Anderson, and Eakle.

EUREKA EARTHQUAKE, JANUARY 31, 1922

BY JAMES B. MACELWANE

(*Abstract*)

This earthquake was quite violent, but did little damage because of the predominance of unusually long periods throughout the motion. The propagation and modification of phases was studied in great detail and followed more than two-thirds of the way to the antipodes by means of original records or photographic copies kindly lent for the purpose by fifty-one seismographic stations and by reports from fifteen others. The epicenter was found to be in latitude 41° 8′ + or — 3′ north and longitude 125° 30′ + or — 3′ west. Was it connected with the San Andreas Rift? A comparative study of wave periods yielded two surprising results. In the first preliminaries the records at nearby stations showed a long wave with a very short wave superposed on it. The farther the station was from the epicenter, however, the shorter the period of the longer wave became and the longer that of the shorter, until they blended into one in the central United States. Secondly, the periods of the maximum waves were found to increase progressively as a function of the distance, at least throughout the first quadrant.

Presented extemporaneously and illustrated by lantern slides.

FAULTING IN THE WESTERN PART OF SAN GABRIEL MOUNTAINS

BY WILLIAM S. W. KEW

(*Abstract*)

San Gabriel Mountains represent the eastern part of the general east-west trending system of mountains extending from Point Conception west of Santa

Barbara to the San Gorgonio Mountains, which is one of the main structural as well as physiographic features in California. In the western part, where the rocks are mainly sedimentaries, the compressive movements produced along this diastrophic zone have been expressed by acute folding modified by faulting, whereas in the eastern part, where the rocks are largely crystalline, a complex system of faulting with comparatively little folding has resulted. The mapping of the region north of Los Angeles has brought out many intricacies in the faulting between the sedimentary and crystalline rocks which show that the San Gabriel massif, at least in its western part, has not been elevated as a single block, but has been broken by numerous faults. The south front of the range is composed of a series of small blocks dropped down and tilted as if broken off from the main mass when it was uplifted. Sediments which once covered a part of the range still remain on a part of the mountains and terrace deposits occur in places high up on the slopes.

North of Los Angeles three main faults have caused the crystalline rocks and superposed sedimentaries, which are a part of the whole San Gabriel province, to be step-faulted with blocks tilted northward. The southernmost fault is located on the north side of Eagle Rock Valley, west of Pasadena. The second is on the north side of San Fernando Valley and at the base of the prominent scarp of San Gabriel Mountains, east of Sunland. The Santa Susana thrust is the westward continuation of this fault. The third lies about two miles north of the second fault and within the mountains, where it forms the valley-like depression at the head of Little Tujunga Canyon. An east branch of this fault passes into the canyons of the east and west branches of the upper part of San Gabriel River; the westward extension beyond the range continues for ten miles as a fault in the sedimentary rocks, beyond which point the stresses have been relieved by folding in the Topatopa anticlinorium.

This faulting probably began at the close of the Miocene period and continued into Recent time. Evidence of faulted Pleistocene terrace deposits are present in places. It is thought possible that the theory of isostasy can be used as a basis for the explanation of the origin of San Gabriel Mountains.

Read from manuscript and illustrated by lantern slides. Discussed by Messrs. F. M. Anderson, Turner, Tolman, Trask, Buwalda, Louderback, and Blackwelder.

GEOLOGY OF THE HYDROGRAPHIC BASIN OF THE UPPER SANTA YNEZ RIVER, CALIFORNIA

BY RICHARD N. NELSON

(*Abstract*)

The rocks of the district range in age from Jurassic to Pliocene. The Franciscan group, which is the oldest in the area, includes metamorphic and other types of rocks common to this group throughout the Coast Ranges. The Franciscan is succeeded by a great thickness of sandstone and shales, with some conglomerates and impure limestones, which contain fossils of Knoxville-Lower Cretaceous age. The Chico-Upper Cretaceous is represented by large amounts of sandstones and shales and a small amount of conglomerate. Depo-

sition of the Cretaceous was followed by a period of erosion and deformation, during which the sediments were stripped off down to the Franciscan in places. This period may correspond to the Martinez-Lower Eocene, of which there is no record in the district, although it is well developed in regions to the north and south. The lowest known Eocene horizon is the Meganos-Middle Eocene, which comprises sandstones, shales, and limestones. The Tejon-Upper Eocene is also present. It consists of shales resting upon massive sandstones which appear conformable with the Meganos. The Eocene is unconformably overlain by the Sespe-Oligocene, a formation of continental origin. The Sespe-Oligocene is followed by sediments of the Monterey-Miocene series. These are divided into three lithologic units: Temblor sandstone at the base, followed by the Salinas shale, which is overlain, in part, by a sandstone given the name Tequepis sandstone. The Monterey series is unconformably overlain by the Fernando-Pliocene consisting of a small amount of conglomerate and sandstone, which gives way to gravels, sands, and clays appearing to be the equivalent of the Paso Robles-Upper Pliocene. The Quaternary is represented by terrace, fan, and recent alluvial deposits.

The rocks of the district have been very much disturbed by folding and faulting. Most of the faults have a trend slightly north of west, except in the southwest part of the district, where they run more nearly east and west. Both normal and reverse faults occur. The folds are closely related to the faulting. The greatest movements are post-Pliocene in age.

A series of well developed terraces shows the most recent movements to have been general uplifts.

Presented extemporaneously, with charts, sections, and maps. Discussed by Messrs. Louderback, Kew, and Tolman.

EVEN-CRESTED RIDGES AS EVIDENCES OF FORMER PENEPLANATION

BY JOHN P. BUWALDA

(*Abstract*)

It is probable that certain erosional processes tend to reduce rather than accentuate the unevenness of the longitudinal profile of ridges. It does not seem justifiable, therefore, to assume generally that the even crests of ridges imply peneplanation without additional evidence of another type.

Presented from notes. Discussed by Mr. Louderback.

NOMENCLATURE OF SEDIMENTATION

BY ELIOT BLACKWELDER

(*Abstract*)

Suitable definite terms are an obvious necessity in any science. There is probably no subdivision of geology which is more afflicted by its terminology and the lack of it than sedimentation. Assuming that improvement is not only necessary, but possible, what is the best way to bring it about?

Presented extemporaneously at the dinner. Discussed by Messrs. Louderback and Lawson.

ANNUAL DINNER

The dinner, under the auspices of the Le Conte Club, was given at the Faculty Club. After Mr. Blackwelder's paper, short informal communications on various geologic topics were offered by several members.

REGISTER OF THE 1923 MEETING

FELLOWS

F. M. ANDERSON
ELIOT BLACKWELDER
J. P. BUWALDA
B. L. CLARK
E. T. DUMBLE
A. S. EAKLE
W. S. W. KEW
A. C. LAWSON
G. D. LOUDERBACK
A. F. ROGERS
C. F. TOLMAN
H. W. TURNER

GUESTS

E. BADDLEY
L. A. BOND
P. BYERLY, JR.
C. L. CAMP
E. L. DE MARIS
Q. S. DIVEN
M. G. EDWARDS
A. H. ELFTMAN
H. O. ELFTMAN
H. S. FORGERON
E. L. FURLONG
G. D. HANNA
R. T. HAZZARD
G. W. HEID
L. G. HERTLEIN
I. K. HOWETH
D. D. HUGHES
C. D. HULIN
M. C. ISRAELSKY
J. B. LEISER
H. B. LLOYD
O. G. MCDONALD
J. B. MACELWANE
C. E. MEEK
R. P. MILLER
A. F. MORRIS
R. R. MORSE
F. A. MOSS
R. N. NELSON
W. M. NICHOLLS
O. G. ODEN
E. L. PACKARD
R. D. REED
G. O. SCARFE
M. B. SCHMITTON
C. STOCK
C. M. STOLLINGS
H. D. SUTLIFFE
F. H. THOMAS
H. R. THORNBURGH
H. G. TICKELL
A. J. TIEJE
P. D. TRASK
F. L. WRIGHT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 169-200 MARCH 30, 1924
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE FIFTEENTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT WASHINGTON, D. C., DECEMBER 27-29, 1923.

R. S. BASSLER, *Secretary*

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Session of Thursday, December 27

The preliminary business meeting, held usually at the first session of the Society, was postponed until Friday morning in order that the members could meet in joint session with the Geological Society of America on Thursday morning. At 12.30 the address of Dr. T. Wayland Vaughan, retiring President of the Paleontological Society, was delivered before all the affiliated societies in the auditorium of the Interior Building. As the presidential address formed the introductory paper of the symposium planned as the main feature of the meeting, an outline of its principal features is here presented.

CRITERIA AND STATUS OF CORRELATION AND CLASSIFICATION OF TERTIARY DEPOSITS

PRESIDENTIAL ADDRESS BY T. WAYLAND VAUGHAN

(*Abstract*)

This paper briefly reviews the essential principles utilized in geologic correlation, with particular reference to Tertiary deposits. After defining the

geologic terms formation, member, group, and stage, the necessity of type localities for stratigraphic units is emphasized and the construction of standard stratigraphic sections and time scales is discussed. The biologic method of correlation is considered in some detail and the defects of both the Lyellian method and inference from supposedly known stratigraphic ranges of species and genera are pointed out. The effects of barriers on geographic distribution, unequal rates of evolution in different areas, and rates and means of migration from one area to another are discussed in their bearing on problems of correlation, and more detailed and comprehensive investigation of the duration of the free-swimming larval stages of marine organisms is urged. The value of interdigitating terrestrial and marine organisms in correlation is stated.

The previous attempts to correlate American with European Tertiary formations are briefly outlined; the defects and the causes of the defects of these attempts are discussed and suggestions for remedying them are made.

The importance of the American Tertiary formations in solving problems of world-wide correlation of Tertiary formations is stated, and more thorough and comprehensive investigations of the stratigraphy and paleontology of Central America and the West Indies is specially urged.

The principal units of the classification of European Tertiary deposits are listed, and reference to the original publication, the source of the name, the type locality, and the general features of each limit are given. The paper closes with a similar list of units in the classification of the Tertiary deposits of southeastern North America, Central America, and the West Indies.

The societies then adjourned for luncheon.

At 2 p. m. the Paleontological Society met in the conference room of the Director, United States Geological Survey, and, with Doctor Vaughan in the chair, proceeded with the reading of the symposium papers.

SYMPOSIUM ON THE CORRELATION OF THE TERTIARY FORMATIONS OF SOUTHEASTERN NORTH AMERICA, CENTRAL AMERICA, AND THE WEST INDIES WITH THE TERTIARY FORMATIONS OF EUROPE

The first paper was presented by the author. Discussion was reserved until the presentation of all papers had been completed.

TERTIARY TERRESTRIAL VERTEBRATE HORIZONS OF NORTH AMERICA

BY W. D. MATTHEW

In the unavoidable absence of the author, the second paper had to be read by title.

INTERDIGITATION OF AMERICAN TERTIARY TERRESTRIAL VERTEBRATES WITH MARINE DEPOSITS

BY J. C. MERRIAM

The next speaker discussed the geographic distribution of living pelagic vertebrates and the geologic occurrence of North American Tertiary cetaceans, comparing the various American faunas with those of Europe.

TERTIARY PELAGIC VERTEBRATES OF EASTERN NORTH AMERICA

BY REMINGTON KELLOGG

The floras of the various stages of the Tertiary of southeastern North America were compared with those of Central America, the Antilles and northern South America, and the present status of their correlation with one another, with the standard marine section, and with the Tertiary floras of Europe were discussed in the next paper.

AMERICAN TERTIARY TERRESTRIAL PLANTS AND THEIR INTERDIGITATION WITH MARINE DEPOSITS

BY E. W. BERRY

President Vaughan then presented the data afforded by the larger foraminifera and corals.

AMERICAN AND EUROPEAN TERTIARY LARGER FORAMINIFERA AND CORALS

BY T. WAYLAND VAUGHAN

(*Abstract*)

Most of the genera of larger foraminifera common to Europe and America have similar, or nearly similar, stratigraphic ranges on the two continents, as is shown by the following data on their stratigraphic distribution in America. No large *Nummulites*, such as are common in Eurasia, are known in America. Small species, probably not true *Nummulites*, range from deposits of middle Eocene age to middle and perhaps uppermost Oligocene. *Operculina* ranges from middle Eocene to the Tuxpan Miocene. *Heterostegina* ranges from upper Eocene to the top of the Culebra formation, probably Aquitanian. Species referred to the nomenclatorially invalid genus *Orthophragmina* range from Claibornian or slightly lower Eocene to uppermost Eocene. The species referable to *Asteriacites* of Schlotheim and similar forms are known only in the upper Eocene. *Cycloclypeus* and *Assilina* are unknown in America. Lepidocycline foraminifera of *Lepidorbitoides* facies are abundant in the upper Eocene; true *Lepidocyclina* ranges from upper Eocene to the horizon of the Emperador limestone, probably the equivalent of the Aquitanian. *Helicolepidina* is known only in the upper Eocene of America. *Miogypsina* is known in the upper part of the Culebra formation, the Emperador limestone, and the Anguilla formation, in deposits probably the equivalent of the European Aquitanian. *Dictyoconus* ranges from the middle Eocene Plaisance limestone of Haiti to the middle Oligocene Glendon limestone in Florida. *Sorites* ranges from the Culebra formation to Recent. *Alveolina* is common in the Eocene of Jamaica, and is represented by a small species in younger deposits.

Lepidocyclina s. s. (type *L. mantelli*) in America seems to attain its maximum development earlier than in Europe. In America this development is upper Eocene and lower and middle Oligocene, but the genus is represented in deposits probably the equivalent of the Aquitanian.

The principal tie points between the American and European coral faunas are, as I have already published, the upper Eocene Saint Bartholomew limestone with the Priabonian of Italy and the lower part of the Antigua formation and the Glendon limestone of Florida and Georgia with the Rupelian of Castel Goberto and other places in northern Italy.

A paper by Dr. G. Stefanini, of Florence, Italy, newly elected Correspondent of the Society, dealing with the correlation as shown by the echinoids, was read by C. W. Cooke.

AMERICAN AND EUROPEAN TERTIARY ECHINOIDS

BY G. STEFANINI

The value of the bryozoa in intercontinental correlation and other features of geologic interest exhibited by these organisms were indicated in a paper read by R. S. Bassler.

AMERICAN AND EUROPEAN TERTIARY BRYOZOA

BY F. CANU AND R. S. BASSLER

The remaining papers of the symposium dealt with the molluscan evidence. The first of these was concerned with the early Tertiary faunas.

AMERICAN AND EUROPEAN EOCENE AND OLIGOCENE MOLLUSCS

BY C. WYTHE COOKE

(*Abstract*)

An important tie point in the correlation of the American and European formations is the faunal break between the Eocene and Oligocene. Less than 9 per cent of the molluscs in the Red Bluff clay (lower Oligocene) are survivors from the Eocene, and the proportion for the entire Vicksburg group is considerably less. Fewer than 5 per cent of the molluscs in the large Sannoissian fauna are Eocene species. Both above and below this break the generic assemblages on both sides of the Atlantic are similar.

Direct comparison of American with European forms has been hampered by the lack of representative collections from many foreign localities, but many similar, possibly identical species can be cited. Some of these are characteristic Eocene or Oligocene species, but range through several formations. In general, therefore, precise correlations between American and European formations based only upon our present knowledge of the molluscs are not practicable.

The later Tertiary mollusca were discussed in the next paper.

COASTAL PLAIN AND EUROPEAN MIOCENE AND PLIOCENE MOLLUSCS

BY JULIA GARDNER

(*Abstract*)

The fauna of the Chipola marl at the base of the Alum Bluff and of the Miocene approaches more closely to a tropical fauna than does any other Miocene fauna of the southeastern United States. On the basis of the stratigraphic position of Central American and West Indian faunas of the same age the relationship of the Chipola to the Burdigalian fauna of southwestern France may be traced. With the gradual cooling of the waters in the later Alum Bluff, many of the tropical species disappear and the affinity of the later Alum Bluff to the Burdigalian of southern Europe becomes more obscure. The most pronounced faunal break in the Neocene of the East Coast occurs at the close of the Shoal River. The tropical species are swept away by the influx of cooler waters from the north and supplanted by a fauna remarkably homogeneous from Maryland to Florida and comparable to that of north-central Europe. In the later Miocene there is a gradual readjustment and an approximation to modern conditions. A warm current allowed the southern faunas to reestablish themselves, to a certain extent, as far north as Hatteras. A comparison of the Duplin and Choctawhatchee may be made with the Sarmation and Tortonian of southern Europe, but the correlation of the Yorktown with the Upper Miocene of Europe is less direct. The relationship of the East Coast Pliocene faunas to those of the Pliocene of Europe is closely analogous to the relationship of the East Coast Recent and European faunas.

The final paper of the symposium, illustrated by numerous charts, was then presented.

WEST INDIAN, CENTRAL AMERICAN, AND EUROPEAN MIOCENE AND PLIOCENE MOLLUSCS

BY W. P. WOODRING

(*Abstract*)

The Miocene deposits of the West Indies and Central America contain rich tropical faunas of probably 2,000 species of molluscs, of which not more than half have been described. Pliocene deposits so far explored have yielded only a meager fauna. These West Indian and Central American faunas are compared with essentially similar faunas of two classic European Tertiary basins, the Aquitaine basin of France and the Piedmont basin of Italy.

The composition of the American and European faunas, based on the genera, is graphically shown on charts. The American faunas are predominantly West Indian. Their most striking exotic element is a group of genera now living only in the Pacific Ocean or in the Indo-Pacific region. The European faunas have a much larger percentage of exotic genera. The largest group of living exotic genera is West Indian. Other exotic genera are living both in the West Indies and along the West African coast; others only along the coast of West Africa, especially along the Senegalese coast. The European

faunas have an even larger percentage of Pacific and Indo-Pacific genera than the American faunas, but for the most part these genera in the two regions are different.

Almost all the exotic genera in the European deposits now living in the West Indies, or in both West Indian and West African waters, are common West Indian and Central American Miocene fossils. For this reason there is a striking resemblance between these American and European Miocene faunas. This resemblance reaches its culmination in the Helvetian faunas, as is shown in a graph.

A general discussion of the problems brought out in the symposium followed the concluding paper, and the subject of the smaller foraminifera which had not been considered was especially reviewed.

At 5 p. m. the Society adjourned until the following day.

Thursday evening at 7.30 the members met in the auditorium of the Interior Building with the other affiliated societies to hear the address of Mr. David White, retiring President of the Geological Society of America and former President of the Paleontological Society. Mr. White's address was entitled "Gravity observations from the standpoint of local geology."

Following this address the members were tendered a complimentary smoker by the Geological Society of Washington.

Session of Friday, December 28

President Vaughan called the fifteenth annual meeting of the Society to order in business session, at 9.15 a. m., December 28, in the Director's conference room, and after welcoming the members to Washington requested the reading of the report of the Council.

Report of the Council

To the Paleontological Society in fifteenth annual meeting assembled:

The Society's business for the year has been transacted by two formal meetings of the Council and by correspondence.

Secretary's Report

To the Council of the Paleontological Society:

Meetings.—The proceedings of the fourteenth annual meeting, held at Ann Arbor, Michigan, December 28-30, 1922, have been printed in volume 34, number 1, of the Bulletin of the Geological Society of America, pages 121-142. The Council's proposed nominations for officers for

1924 was mailed to the members on March 1, 1923. At the same time it was announced that the fifteenth annual meeting would be held at Washington, D. C., December 27-29, 1923, as guest of the Geological Society of Washington, and that a symposium on the "Correlation of the Tertiary formations of southeastern North America, Central America, and the West Indies with the Tertiary formation of Europe" was proposed for this meeting.

Membership.—The Society has lost four of its members during the year by death—Mr. Thomas A. Bostwick, well known for his long service in the care of the paleontological collections at Peabody Museum, Yale University, and Mr. Edgar E. Teller, General Anthony W. Vogdes, and Mr. George F. Matthew, three active students of invertebrate paleontology who have done much to further the science by their work and publications. Six new members have just been elected to the Society and five nominations are awaiting consideration at this meeting. Five of our members have been elected this year to Fellowship in the Geological Society of America and one Fellow of the latter Society has requested election to our own Society. The result of these various changes leaves a total number of members at the end of 1923 of 239.

Publications.—The publications of the Society for the year consist of the Proceedings, the Presidential address, and three papers on vertebrate paleontology, all appearing in the Bulletin of the Geological Society of America.

Dr. R. S. Lull represented the Society at the Joseph Leidy Commemorative Meeting, held at the Philadelphia Academy of Natural Sciences, December 6, 1923.

The Council appointed Dr. Arthur Hollick, on March 10, 1923, as the representative of the Society on Botanical Abstracts, succeeding Dr. E. W. Berry, whose term had expired.

During the year the Council has cooperated with the Geological Society of America in an effort to more logically classify the papers presented at the meeting by the various affiliated societies, and especially to arrange a program in which papers of general interest would not conflict. Several circular letters regarding this subject were sent to the members during the course of the year. It is believed that the program as arranged for the present meeting, providing for joint sessions of the affiliated societies for the presentation of papers of general interest, obviates most of the points under criticism.

Pacific Coast Branch.—The meeting of the Pacific Branch of the Paleontological Society was held on September 18, at the Los Angeles Museum of History, Science and Art, Exposition Park, with Vice-President

A. O. Woodford presiding. Ten papers dealing particularly with the stratigraphy and paleontology of the West Coast were presented.

Respectfully submitted, R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 26, 1923.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 22, 1923:

RECEIPTS

Cash on hand December 23, 1922	$802.22	
Membership fees	288.00	
Interest, Connecticut Savings Bank	29.64	
		$1,119.86

EXPENDITURES

Secretary's office:			
Secretary's allowance	$50.00		
Clerical aid	25.00		
Office expenses	48.00		
		$123.00	
Treasurer's office:			
Treasurer's allowance	$25.00		
Postage	4.00		
		29.00	
Geological Society of America:			
Printing programs, etcetera	$9.25		
Reprints	28.00		
		37.25	
			189.25
Balance on hand December 22, 1923			$930.61
Net increase in funds			$128.39
Outstanding dues (1922, 4; 1923, 24)			84.00

Final statement of retiring Treasurer, 1911-1923:

Received from W. D. Matthew, 1911	$141.91
To be paid to C. O. Dunbar, 1923	930.61
Net increase in funds	$788.70

Liabilities due at this time, none.

Respectfully submitted, RICHARD S. LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 22, 1923.

APPOINTMENT OF AUDITING COMMITTEE

Following the report of the Council, President Vaughan appointed Messrs. Resser and Twenhofel as a committee to audit the Treasurer's accounts.

ELECTION OF OFFICERS AND MEMBERS

The result of the election of officers for 1924 and of new members was then read as follows:

OFFICERS FOR 1924

President:

E. W. BERRY, Baltimore, Maryland

First Vice-President:

E. H. BARBOUR, Lincoln, Nebraska

Second Vice-President:

FRANK SPRINGER, Washington, D. C.

Third Vice-President:

F. M. ANDERSON, Berkeley, California

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

CARL O. DUNBAR, New Haven, Connecticut

Editor:

WALTER GRANGER, New York City

NEW MEMBERS FOR 1924

JOHN H. BRADLEY, JR., 5640 Woodlawn Avenue, Chicago, Illinois.
HARRY S. LADD, Old Science Hall, University of Iowa, Iowa City, Iowa.
ERWIN R. POHL, U. S. National Museum, Washington, D. C.
MERRILL A. STAINBROOK, Old Science Hall, University of Iowa, Iowa City, Iowa.
FRANKLIN E. VESTAL, Department of Geology, Agricultural College, Mississippi.
BRADFORD WILLARD, Department of Geology, Brown University, Providence, Rhode Island.

NEW NOMINATIONS AND ELECTION TO MEMBERSHIP

The following five nominations to membership arriving too late for printing on the ballot had received the approval of the Council and were now presented for action by the Society. In turn the qualifications of each nominee were presented to the members. All received election upon vote:

T. D. A. COCKERELL, 905 Tenth Street, Boulder, Colorado. Professor of Zoology, University of Colorado. Proposed by R. S. Bassler and E. O. Ulrich.

EUSTACE L. FURLONG, 1031 Glendora Avenue, Oakland, California. Curator of Mammals, Museum of Paleontology, University of California. Proposed by Ralph W. Chaney and Chester Stock.

MURRAY O. HAYES, Assistant Professor of Geology, Brigham Young University, Provo, Utah. Proposed by E. O. Ulrich and R. S. Bassler.

ALLEN TESTER, graduate student, Department of Geology, University of Wisconsin, Madison, Wisconsin. Proposed by W. H. Twenhofel and R. C. Moore.

J. B. WINSTANLEY, 2818 Orchard Avenue, Los Angeles, California. Proposed by Ralph W. Chaney and Chester Stock.

Mr. F. Julius Fohs, elected to Fellowship in the Geological Society of America, requested enrollment in the membership of the Paleontological Society. Upon vote, Mr. Fohs was duly elected a member.

ELECTION OF CORRESPONDENTS

President Vaughan then reported that the Council favored the election as Correspondents of three distinguished foreign geologists and paleontologists—Dr. F. A. Bather, of England; Prof. G. Stefanini, of Italy, and Dr. G. E. Pilgrim, of India—in view of their important contributions to our science. The work of Doctor Bather was reviewed by R. S. Bassler, that of Doctor Pilgrim by President Vaughan and W. D. Matthew, and of Professor Stefanini by E. W. Berry. Upon vote, these three scientists were unanimously elected.

Dr. F. A. BATHER, British Museum (Natural History), London, England.
Prof. G. STEFANINI, Real Istituto di Geologia e Paleontologia, Florence, Italy.
Dr. G. E. PILGRIM, Superintendent, Geological Survey of India, Calcutta, India.

NECROLOGY

President Vaughan then recalled the Society's loss by death during the year of four members, and first requested Professor Dunbar to present some remarks upon the life of Mr. Bostwick. Professor Dunbar spoke as follows:

MEMORIAL OF THOMAS A. BOSTWICK

Thomas Attwater Bostwick was born in New Haven, Connecticut, November 29, 1859, the son of Frederick L. and Elizabeth Rowland Bostwick. At the age of eighteen he entered the service of Professor Marsh, enrolling at the same time as a special student in Sheffield Scientific School, and six years later, two years after the erection of Peabody Museum at Yale, joined its staff as an assistant. This was the beginning of a long and faithful service which he fulfilled until his very last days. During the earlier years he accompanied Marsh and Beecher on several fossil-hunting expeditions, and throughout the intervening years he journeyed to many parts of the country to pack and ship the numerous important natural history collections that from time to time have been generously given to Yale. He was the only member of the staff whose services were continuous from the founding of the Museum until the razing of the old building in 1917, and his knowledge of our vast collections was, therefore, irreplaceable.

In 1888 Mr. Bostwick married Emily Farnsworth, who survives him. His gentleness of manner and thoughtfulness of others were outstanding characteristics of a personality that knew only friends, and his quiet and unselfish devotion to his work rendered his services in Peabody Museum almost invaluable.

Dr. W. D. Matthew then spoke of his father's life and work. His remarks are summarized below.

MEMORIAL OF GEORGE F. MATTHEW

George Frederic Matthew was born at Saint John, New Brunswick, Canada, August 12, 1837, of United Empire Loyalist parentage, the family having come originally from Dundee, Scotland. From the age of sixteen until a few years before his death he was on the staff of the Saint John Custom Service as surveyor of the port at the time of his retirement. He was interested as a boy in natural history, especially geology and botany. With Charles Frederic Hartt and other young men he founded the Steinhammer Club, later developed into the Natural History Society of New Brunswick. Many of the results of his earlier geologic work were included in Dawson's Acadian Geology. After confederation, the Geological Survey of Canada undertook the mapping of the provinces, and Matthew was employed on field-work for several seasons, mostly with Bailey and Ellis, in southern New Brunswick. The great Saint John fire of 1877 was a heavy loss to him and destroyed his library, herbarium, and geological collections, unpublished notes and records, and he limited himself after that time to work in Cambrian paleontology, subsequently extending it to later Paleozoic formations, but chiefly in and near Saint John.

He was generally regarded as one of the principal contributors to the earlier knowledge of the geology of New Brunswick, and especially to the paleontology of the Cambrian of that region, its glacial and postglacial history, and the difficult and still unsettled problems of its later Paleozoic formations. His views as to the age of the latter, based upon the stratigraphic evidence, brought down upon him the denunciations of the official school of paleobot-

anists; but as none of his critics have re-examined the stratigraphy, the matter should be held *sub judice*.

Although not a college graduate, my father was widely read and well informed in many branches of natural history. He had an honorary doctorate from Laval University, was a charter member of the Royal Society of Canada, a Fellow for many years of the Geological Society of London and the recipient of its Wollaston Medal; a corresponding member of the old New York Lyceum of Natural History and of its successor, the Academy of Sciences; but his chief interest lay with the work of the local Natural History Society, in which he took an active part at all times, and for many of his later years as president of the Society. He was elected a member of the Paleontological Society in 1920. He died at Hastings-on-Hudson, New York, April 17, 1923, in his eighty-sixth year. He married, in 1868, Katherine M. Diller, of Brooklyn, New York, and had a family of six sons and two daughters. The oldest son, who has the honor to contribute this brief notice, follows in his father's footsteps.

Personally, my father was a somewhat reserved and silent man, upright, modest and unselfish, and deeply imbued with the love of nature. He was held in high respect and affection by those who knew him well.

The Secretary presented the following résumé of the life of Mr. Edgar E. Teller, which had been kindly furnished by Mrs. Teller.

MEMORIAL OF EDGAR E. TELLER

Edgar Eugene Teller was born in Buffalo, New York, August 3, 1845, the son of George D. and Susan Brown Teller. He received his education in Buffalo's public and private schools, attending the Central High School, and from there going to Lewiston Academy, at Lewiston, New York, where he received an appointment to Annapolis from the Hon. John Ganson, M. C.; but before he was to enter on his studies he met with an accident, breaking his wrist, thereby incapacitating him for naval service.

The Civil War came on about this time, and the young man desired to enlist, but was refused, due to his youth. Finally he was allowed to go and the boy served through two years under Capt. Theo. D. Barnum, Infantry, B Company, 74th Regiment. At the call for troops at the first of Gettysburg raid they went to the front, and after serving on the field for some time the regiment was sent up the Hudson River, stopping at all places on the way to Sing Sing, returning to New York City, performing important duty at these several points in quelling draft riots; then back to Buffalo, where they were mustered out.

He then entered the employ of his father and several years later, in 1869, he married Marie E. Deeves, of Buffalo. Leaving the family home in Buffalo, Mr. Teller went to Milwaukee, Wisconsin, and entered the employ of Plankinton & Armour, pork packers, in 1875, and shortly afterward was appointed buyer for the firm at the Milwaukee livestock yards. He continued in this capacity successively with Plankinton & Armour, John Plankinton & Company, Cudahy Brothers, and Cudahy Brothers Company, until he retired in 1915, after an unbroken connection with the latter-named company and its

predecessors for forty years. After the death of his only son in that same year, he returned to Buffalo to make his home.

It was during his early days in Milwaukee that he first became interested in geology. In going from his home to business he had occasion to walk through a quarry—a short cut, where he would stop and watch the men at work—and as time went on made the acquaintance of Doctor Day, of Wauwatosa; Doctor Hoye, of Racine; Mr. Thomas A. Greene, and Mr. Chas. E. Monroe, of Milwaukee, all prominent collectors.

Aside from his business association, Mr. Teller took a deep interest in local paleontology, in which field of science he was an authority. He was also interested in other departments of natural history, and particularly in archeology. Elected as a member of the Wisconsin Natural History Society March 3, 1885, he became very active in the archeological section of it.

Mr. Teller was made recording secretary of the Wisconsin Historical Society December 19, 1887, and was elected president of the Society in 1889, and re-elected to the presidency at various intervals almost up to the time of leaving Milwaukee.

By the year 1899 the Archeological Section of the Natural History Society had a very active membership, and largely through the efforts of Mr. Teller and coworkers the membership increased to such strength that in the year 1901 it separated from the parent Society and was incorporated as "The Wisconsin Archeological Society."

It is at present a strong and active Society, and in the twenty-three years of its existence has accomplished much in the way of exploration, recording, and preserving of Wisconsin Indian antiquities. Mr. Teller was one of the active and enthusiastic members and accompanied all of its early field explorations and researches, especially in Milwaukee and Waukesha counties of Wisconsin.

Mr. Teller invariably attended and presided over all of the Wisconsin Archeological Society meetings, and with other members helped to lay the firm foundations upon which the long and successful labors for the public and anthropological science has been based.

A group of Indian effigy and burial mounds, designated as the "Teller Group," were located near the Milwaukee cement mills, at the northern limits of the city, and were named at that time in honor of Mr. Teller's work in their discovery. A part of this group is still in existence. The group is fully described and illustrated in the Bulletin of the Wisconsin Natural History Society for the years 1900-1902.

Some of the most notable works contributed to the Society by Mr. Teller are described in papers and records listed hereunder.

March 14, 1887. Paper read by Edgar E. Teller, "Geology and paleontology of eastern Wisconsin." Wisconsin Natural History Society Bulletin.

April-May, 1899. "The fauna of Devonian formation at Milwaukee, Wisconsin." Printed in the Journal of Geology, volume 7, number 3. "The Teller group of mounds in Milwaukee County." Introduced to the Society by Edgar E. Teller in May, 1899. Described in Bulletin of the Wisconsin Natural History Society, volumes 1 and 2, 1900-1902.

"Notes of the fossil fish-spine *Phlyctænacanthus Telleri*." Published in the Wisconsin Natural History Society Bulletin, volumes 3 and 4, 1903-1906.

"An operculated gastropod from the Niagara formation of Wisconsin." Transactions of the Wisconsin Academy of Sciences, Arts, and Letters, volume 16, part 11, 1909-1910.

"A synopsis of the type specimens of fossils from the Paleozoic formations of Wisconsin." Bulletin of the Wisconsin Natural History Society, volumes 9, 10, 1911, 1912.

On Mr. Teller's return to Buffalo, in 1915, he was elected vice-president of the Buffalo Society of Natural Sciences.

His death, on July 19, 1923, interrupted his work of reclassifying his large collection, but the contributions from his pen, published in periodicals dealing with geological field-work, will remain as a record of his service in this sphere.

During his life Mr. Teller gave the University of Chicago over one hundred thousand specimens as a working collection for the students. He also gave to the Public Museum, in Milwaukee, and to the American Museum of Natural History, in New York, large numbers of specimens; to the latter several type specimens, among them a new species and a new genus of Phyllocarida (*Entomocaris Telleri*). Ten thousand selected specimens were presented to the Buffalo Society of Natural Science.

Dr. Resser then gave the following brief account of General Vogdes' life:

MEMORIAL OF ANTHONY W. VOGDES

General Anthony Wayne Vogdes was born at West Point, New York, in 1843, being descended from General Anthony Wayne on his mother's side. His father and grandfather were generals in the United States Army. He entered the Civil War as a drummer, but was soon commissioned a second lieutenant. After the Civil War he decided to remain in the army, and as a second lieutenant he was detailed to guard the Union Pacific Railroad during building. It was while on this service that he began both his library and collection of fossils.

General Vogdes rose to the rank of brigadier-general before retirement, when he moved to San Diego, California, where he was formerly stationed. His means were never large, so that the splendid library accumulated by him represents much personal sacrifice. This library, now the property of the San Diego Society of Natural History, of which General Vogdes was president for fifteen years, includes about 40,000 titles. Many of the books are beautifully bound by General Vogdes himself, who was very proficient in this work. The fossil collections, also left to the same Society, contains a very large and fine assemblage of trilobites.

General Vogdes published a number of papers on paleontology, but is best known for his bibliographic works on Paleozoic crustacea.

The reading of papers was then commenced, with President Vaughan in the chair.

PRESENTATION OF PAPERS

The first paper of the session delivered by the author brought forth a discussion from several members.

SUBDIVISIONS OF THE CAMBRIAN

BY C. E. RESSER

(*Abstract*)

A threefold subdivision of the Cambrian strata is usually made, following a long-standing custom. These subdivisions are designated as Lower Cambrian characterized by trilobites of the family Mesonacidæ, Middle Cambrian containing *Paradoxides*, and Upper Cambrian with *Dikelocephalus*. This subdivision was made in Sweden for the rather specialized conditions obtaining there, but is applicable beyond the faunal province to which Sweden belongs.

The existence and character of what may be called the Atlantic Province is usually not appreciated. For practically all of Cambrian time and during long intervals in later periods the animals living in this province were all confined to it. The boundary or barrier line, traced approximately, runs north through central Massachusetts, through New Brunswick and central Newfoundland, thence across the Atlantic, possibly with an embayment reaching Greenland, definitely crossing England in southern Scotland, then across Scandinavia somewhere north of Lake Mjosen. The Cambrian faunas of Esthonia, Bohemia, Sardinia, France, Spain, Morocco, and Portugal belong in this province. Only one undoubted transgression of this barrier is now known, with a second indicated. Therefore no exact correlation is possible between the Cambrian strata within and without this province.

The type section for the Lower Cambrian, as it is now used, is in Nevada. There is a general agreement of the faunas present with the more northerly and eastern beds assigned to the same period. No genera cross the barrier into the Atlantic Province, so that except for the members of the same families there is no agreement. Another problem as yet unsolved is the significance of the phyllopods. Recently an interesting group of phyllopods similar to those formerly found only in the Middle Cambrian has been obtained in British Columbia. Opinions differ regarding the phyllopod faunas in New York and in the Atlantic Province in New Brunswick and Portugal as to whether they belong in the Middle or Lower Cambrian. The question of this boundary is therefore an open one just now.

The type section for the Middle Cambrian is the beds in the Atlantic Province which contain *Paradoxides*. As this genus is completely absent outside of this province no limits can be set to this portion of the Cambrian.

The type section for the Upper Cambrian is that of Wisconsin. This has proven quite satisfactory for North America. In this portion of the Cambrian there is one connection between the American and Atlantic Province faunas. In the lower part of the Conasauga formation of Alabama true *Olenus* and *Agnostus reticulatus* occur associated with certain typical American forms. This is the first definite transgression of the barrier that makes the Atlantic Province so exclusive. We can then assume that most of the *Olenus* series and the Upper Cambrian of the American type section are equivalent in age. Definite limits can not, however, yet be drawn.

Recently obtained data indicate that some of the upper beds formerly included in the Cambrian must be regarded as Ozarkian. Sufficient study has not yet been given to this matter to fix this boundary definitely at all points.

The threefold subdivisions of the Cambrian, while not satisfying all conditions nor allowing the drawing of sharp boundaries, must be retained for the present, recognizing, however, the particular unsolved problems.

A paper on Ordovician stratigraphy was then presented by the junior author, who illustrated it with lantern slides.

OCCURRENCE OF THE COLLINGWOOD FORMATION IN MICHIGAN

BY R. RUEDEMANN AND G. M. EHLERS

(*Abstract*)

The Collingwood formation is typically exposed at Ottawa and in southeastern Ontario. The most western exposures of the formation, which so far have been noted, occur in the vicinity of Little Current, on Manitoulin Island, Ontario.

The occurrence of Collingwood strata farther westward in the Northern Peninsula of Michigan is indicated by the presence of *Ogygites latimarginatus* (Hall) syn. *Ogygites canadensis* (Chapman) and other characteristic Collingwood fossils, collected from blocks of shale and limestone in the drift near the southern limits of Newberry, Luce County, Michigan.

The Collingwood age of the blocks of shale and limestone, found in the drift near Newberry, is suggested by their lithological character as well as their faunal content. This is particularly true in the case of the blocks of shale. In Ontario the Collingwood consists of alternate beds of shale and limestone. It seems very possible that this lithological character of the Collingwood may hold westward as far as the region a short distance north of the southern limits of Newberry, where, unfortunately, the formation is covered by drift.

The Collingwood seems to represent a differential development of a part of the upper Utica of New York, which may indicate either a provincial separation from the Utica sea farther south or, more probably, a separate invasion from another (northeastern) direction. According to the evidence presented in this paper, this invasion extended farther west—at least to the Newberry, Michigan region—than has been hitherto believed.

Interesting occurrences of Pleistocene mammals in Mexico were described in the following paper, presented by the author and illustrated by lantern slides:

SOME PLEISTOCENE MAMMALS AND THEIR OCCURRENCE IN MEXICO

BY E. L. FURLONG

A stratigraphic paper, illustrated by lantern slides, was next on the program.

GEOLOGICAL FEATURES OF THE EASTERN HIGHLAND RIM OF TENNESSEE

BY R. S. BASSLER

(*Abstract*)

The Highland Rim surrounding the Central Basin of Tennessee offers many splendid sections for the study of the formations and of their distribution.

Recent investigation of the Eastern Highland Rim showed marked stratigraphic differences from the rim west of the Central Basin. For example, on the east the geological section comprises only the Hermitage and Cannon formations of the Ordovician and the Chattanooga, Fort Payne, and Warsaw divisions of the Mississippian, while in marked contrast on the western rim the same geologic interval develops the Hermitage, Bigby, Cannon, Catheys, and Leipers formations of Ordovician age, the Waynesville, Fernvale, and Osgood divisions of the Silurian, and the Chattanooga, Ridgetop, New Providence, Fort Payne, and Warsaw divisions of the Mississippian.

Topographically the Eastern Rim is quite distinct, for it usually forms a sharp escarpment, with many narrow ravines cutting back into the rim and having their origin in sink-hole structures.

A description of a huge pelecypod, probably an *Inoceramus* from the Cretaceous of the Mackenzie Valley, Canada, was given in the next paper.

AN ENORMOUS CRETACEOUS PELECYPOD

BY G. S. HUME

A most interesting and curious new dinosaur was then described, with lantern-slide illustrations.

NEW PLATED DINOSAUR FROM THE RED DEER RIVER

BY W. A. PARKS

Dr. W. D. Matthew, at the request of President Vaughan, then gave an interesting extemporaneous account of the work of the American Museum of Natural History Expedition in Mongolia.

EXPLORATION FOR FOSSIL REMAINS IN MONGOLIA

BY W. D. MATTHEW

(*Abstract*)

The Third Asiatic Expedition of the American Museum of Natural History, American Asiatic Association, and Asia Magazine has put in two winters of paleontological work in China and two summers in Mongolia. The geologic and physiographic results in Mongolia are reported upon by Berkey and Morris before the Geological Society. The paleontologic work in charge of Walter Granger was extraordinarily successful. A very large collection of Upper Pliocene mammals was obtained from fissure deposits near Wanhsine, on the upper Yang-tse-kiang, including skulls of *Stegodon*, *Rhinoceros*, a gigantic tapir, gaur, tiger, sand-badger, bamboo-rat (numerous), langhur monkey, several kinds of antelope, etcetera. No human or pre-human remains were found associated with this fauna, although they were to be expected. Two summers' field-work in the desert of Gobi showed that region to be rich in fossils, including a number of faunas of Cretaceous and Tertiary age not yet fully correlated. Two complete skeletons and several more fragmentary specimens of a small primitive iguanodontoid dinosaur were secured in 1922,

and in 1923 a great series of 72 skulls and 12 skeletons of a small ceratopsian dinosaur, together with 25 eggs, probably of this species, were obtained at one locality, and at another a great collection of bones and partial skeletons of various kinds of dinosaurs. All these are probably early to middle Cretaceous, but not yet certainly correlated. A skull of the gigantic rhinoceros *Baluchitherium* was found in 1922, associated with a fauna of some thirty species of smaller mammals, mostly rodents, carnivora, and insectivora of Lower Oligocene age, in part new, the rest related to the Phosphorites fauna of France and the White River fauna of this country. An older horizon explored chiefly in 1923 yielded skulls of *Protitanotherium*, a gigantic masonychid creodont, two or more lophiodonts, and other interesting types. Fragmentary remains representing older Eocene faunas were also discovered, as well as other faunas of later Tertiary age.

These results show that in Central Asia is a region as rich in fossils as the western United States, although not so accessible. A large part of its fauna is wholly new and the affinities of other parts provide the needed clues to the problems of origin and dispersal of many races of animals. It will undoubtedly repay many years' exploration. The chief difficulty is the heavy cost of operations in that region, so remote from railroads and roads. Profitable collecting is possible only in a large way, with wide-cast preliminary reconnaissance, followed by intensive collecting in promising areas, and requires an elaborate, well planned, and expensive organization.

In the absence of the authors, the following papers were read by title:

OZARKIAN-CANADIAN UNCONFORMITY

BY E. O. ULRICH

NEW PEABODY MUSEUM AT YALE UNIVERSITY

BY R. S. LULL

BEEKMANTOWN GRAPTOLITES FROM UTAH

BY T. H. CLARK

NEW OZARKIAN FORMATION IN MISSOURI

BY E. O. ULRICH

OLIGOCENE HICKORY NUTS

BY E. L. TROXELL

COMPARISON OF THE BRIDGE CREEK FLORA WITH THE LIVING REDWOOD FOREST

BY R. W. CHANEY

FEATURING THE GEOLOGY OF PARKS

BY E. L. TROXELL

FORT CASSIN FAUNA

BY E. J. FOYLES

At 12.30 p. m. the Society adjourned.

Friday afternoon was spent in joint session with the Geological Society of America, when the following program of stratigraphic papers was presented, some of them by title only:

GEOLOGIC SECTION ACROSS THE COAST RANGES OF CALIFORNIA

BY GEORGE D. LOUDERBACK

FRANKLIN MOUNTAINS

BY MERTON YARWOOD WILLIAMS

STRATIGRAPHY OF THE CRETACEOUS-EOCENE TRANSITION BEDS IN EASTERN MONTANA AND THE DAKOTAS

BY W. T. THOM, JR., AND C. E. DOBBIN

CHAGRIN FORMATION OF OHIO

BY GEORGE HALCOTT CHADWICK

EROSION BY SOLUTION AND FILL

BY WILLIS T. LEE

NEW FORMATION IN THE TAMPICO EMBAYMENT REGION

BY J. A. CUSHMAN AND EARL A. TRAGER

STRUCTURES IN THE SLATES OF NORTHEASTERN PENNSYLVANIA

BY CHARLES H. BEHRE, JR.

GEOLOGY OF LEVIS, QUEBEC

BY THOMAS H. CLARK

PROPOSED STRATIGRAPHIC SECTION AND CODE

BY GEORGE H. ASHLEY

SUGGESTIONS FOR THE IMPROVEMENT OF OUR GEOLOGIC TERMINOLOGY

BY ELIOT BLACKWELDER

UPPER ORDOVICIAN AT TORONTO, ONTARIO

BY W. A. PARKS

EARLIER SILURIAN FORMATIONS OF PENNSYLVANIA

BY CHARLES K. SWARTZ

KANSAS PERMIAN UNCONFORMITY

BY GEORGE HALCOTT CHADWICK

ORISKANY LIMESTONE IN ILLINOIS

BY T. E. SAVAGE

Friday evening at 6.30 the members attended the annual dinner of the Geological Society of America and affiliated societies, when a program prepared by the Pick and Hammer Club, of Washington, furnished a considerable part of the entertainment.

Session of Saturday, December 29

As the reading of papers had been completed on Friday, no regular session was held on this day. Interested members attended the meetings of the Geological Society of America and the Mineralogical Society; others visited the laboratories and exhibits of the United States National Museum, while still others studied the geology of the Piedmont Plateau and Atlantic Coast Plain, in the vicinity of Washington, under the guidance of a local member.

Register of the Washington Meeting, 1923

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Minutes of the Meeting of the Pacific Branch of the Paleontological Society

The meeting of the Pacific Branch of the Paleontological Society was called to order by Vice-President A. O. Woodford at 9 a. m., September 18, 1923, at the Los Angeles Museum of History, Science, and Art, Exposition Park. The following papers were then read:

PRESENTATION OF PAPERS

FOSSIL CONTENT OF THE SAN RAFAEL LIMESTONE OF THE SAN RAFAEL MOUNTAINS, SANTA BARBARA COUNTY, CALIFORNIA

BY M. C. ISRAELSKY

MARINE EOCENE HORIZONS OF WESTERN NORTH AMERICA

BY B. L. CLARK

STUDY OF THE FAUNAL AND STRATIGRAPHIC RELATIONS OF THE MIDDLE AND LOWER MIOCENE OF THE SANTA ANA MOUNTAINS, SOUTHERN CALIFORNIA

BY C. D. MESERVE

CRETACEOUS DEPOSITS OF THE NORTHERN ANDES

BY F. M. ANDERSON

FOSSIL DIATOMS OF CALIFORNIA FROM A HISTORICAL STANDPOINT

BY C. DALLAS HANNA

The meeting then adjourned for luncheon.

At 2.15 p. m. the meeting was again called to order by Vice-President A. O. Woodford and the following papers were read:

PROTESTING THE SPECIES-MAKER: THE POINT OF VIEW OF THE PRACTICAL PALEONTOLOGIST

BY A. J. TIEJE

WESTERN EXTENT OF THE PAINTED DESERT FORMATION AND ITS FAUNA

BY C. L. CAMP

CLASSIFICATION AND RELATIONSHIP OF THE EDENTATES OF RANCHO LA BREA

BY CHESTER STOCK

PROGRAM FOR FURTHER STUDY OF SUCCESSION OF FAUNAS AND FLORAS IN THE JOHN DAY REGION OF EASTERN OREGON

BY JOHN C. MERRIAM

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BARRELL, JOSEPH. Died May 4, 1919.
BILLINGS, W. R. Died March 1, 1920.
BOSTWICK, THOMAS A. Died April, 1923.
CALVIN, SAMUEL. Died April 17, 1911.
CLARK, WM. B. Died July 27, 1917.
CROZEL, GEORGES. Died October; 1921.
DERBY, ORVILLE A. Died Nov. 27, 1915.
DONEGHY, JOHN T. Died June 29, 1921.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
FONTAINE, WM. M. Died April 30, 1913.
GILL, THEODORE N. Died Sept. 25, 1914.
GORDON, ROBERT H. Died May 10, 1910.
HAMLIN, HOMER. Died in July, 1920.
HARPER, GEORGE W. Died Aug. 19, 1918.
HAWYER, J. C. Died May 15, 1914.
LAMBE, L. M. Died March 12, 1919.
LYON, VICTOR W. Died Aug. 17, 1919.
MATTHEW, GEORGE F. Died Apr. 17, 1923.
MOODY, W. L. Died October 9, 1920.
PROSSER, C. S. Died Sept. 11, 1916.
SEELY, HENRY M. Died May 4, 1917.
TELLER, EDGAR E. Died July 19, 1923.
VOGDES, ANTHONY W. Died Feb. 8, 1923.
WARING, CLARENCE A. Died Nov. 4, 1918.
WILLIAMS, HENRY S. Died July 31, 1918.
WILLISTON, S. W. Died Aug. 30, 1918.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 201-206 MARCH 30, 1924

PROCEEDINGS OF THE FOURTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA, HELD AT WASHINGTON, D. C., DECEMBER 28 AND 29, 1923.

FRANK R. VAN HORN, *Secretary*

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SESSION OF FRIDAY AFTERNOON, DECEMBER 28

At 2 p. m. the Mineralogical Society held a joint session with the Geological Society in the Director's conference room, Interior Building. Dr. E. T. Wherry, President of the Mineralogical Society, presided, and during the afternoon papers of both mineralogical and geological interest were presented.

SESSION OF SATURDAY MORNING, DECEMBER 29

At 9 a. m. a joint session of the Geological Society and Mineralogical Society was held in the auditorium of the Interior Building. Dr. David White, President of the Geological Society, presided, and papers were read which were of combined geological and mineralogical nature.

At 12 o'clock Dr. Edgar T. Wherry, of the Mineralogical Society, gave his presidential address entitled "The surface of a crystal."

Session of Saturday Afternoon, December 29

The Mineralogical Society of America held its fourth annual meeting in the auditorium of the Interior Building, Washington, D. C., in conjunction with the Geological Society of America.

At 1.30 p. m. Samuel G. Gordon gave an interesting illustrated lecture on his recent expedition to the Ivigtut and Kangerdluarsuk regions of Greenland.

At 2 p. m. the meeting was called to order by President Edgar T. Wherry. On motion of the Secretary, the reading of the minutes of the last annual meeting was dispensed with, in view of the fact that they have been printed on pages 46-56 of volume 8, number 3, of the American Mineralogist.

Election of officers and fellows for 1924

The Secretary announced that 101 ballots had been cast for the amendment to the Constitution and for the officers for 1924, as nominated by the Council, and that the list was elected. It is as follows:

President, Henry S. Washington

Geophysical Laboratory, Washington, D. C.

Vice-President, Washington A. Roebling

Trenton, New Jersey

Secretary, Frank R. Van Horn

Case School of Applied Science, Cleveland, Ohio

Treasurer, Alexander H. Phillips

Princeton University, Princeton, New Jersey

Editor, Walter F. Hunt

University of Michigan, Ann Arbor, Michigan

Councilor, A. L. Parsons

University of Toronto, Toronto, Canada

The Secretary also reported that the Council had approved the list of nominations for Fellows, and asked that in view of the fact that the

recent amendment to the Constitution does not go into effect until January 1, 1924, the annual meeting express its approval of the present list of Fellows, and also ratify the action of past Councils on all previous lists. A motion to this effect was made, seconded, and carried. The list of Fellows so approved follows:

HAROLD L. ALLING, University of Rochester, Rochester, N. Y.
G. M. BUTLER, University of Arizona, Tucson, Ariz.
GEORGE L. ENGLISH, Rochester, N. Y.
JOSEPH L. GILLSON, Massachusetts Institute of Technology, Cambridge, Mass.
FRANK L. HESS, United States Geological Survey, Washington, D. C.
PAUL F. KERR, Leland Stanford Jr. University, Stanford University, Calif.
O. IVAN LEE, Newark, N. J.
WILLIAM J. MILLER, Smith College, Northampton, Mass.
ARTHUR E. RUSSELL, Swallowfield Park, Reading, Berks, England.
EDWARD SAMPSON, United States Geological Survey, Washington, D. C.
GEORGE STEIGER, United States Geological Survey, Washington, D. C.
GEORGE VAUX, JR., Bryn Mawr, Pa.
LEWIS G. WESTGATE, Ohio Wesleyan University, Delaware, Ohio.
R. W. G. WYCKOFF, Geophysical Laboratory, Washington, D. C.

REPORT OF THE SECRETARY

The Secretary reported that the roll of the Society now comprises 75 Fellows and 199 members, a gain of 6 Fellows and 32 members for the year. It was also urged that the Society use every effort during the next year to increase the number of Fellows, members, and subscribers in order that further funds may be secured to increase the size of the Journal. Forty-eight Fellows and members, as well as additional guests, attended the meeting, which was the largest in the history of the Society.

REPORT OF THE TREASURER

The report of the Treasurer, A. B. Peck, was read by W. F. Hunt. On motion, an auditing committee, consisting of Dr. W. T. Schaller and William F. Foshag, was appointed by the President. This committee later reported to the Secretary that they found the books of the Treasurer correct.

REPORT OF THE EDITOR

The Editor read his report. which showed a favorable growth of the Journal for the last year, and indicated that the size might be increased without a financial loss on the part of the Society.

REPORT OF THE COMMITTEE ON THE NOMENCLATURE AND CLASSIFICATION OF MINERALS

Prof. Thomas L. Watson, chairman of the committee, read a preliminary report on certain topics, which will be mimeographed and sent to the membership. He moved that the final report on topics 3 and 4 be published in the minutes and printed in the journal. The committee deserves great credit for the large amount of time which they have devoted to the various subjects during the last three years. The committee, besides the chairman, consists of W. F. Foshag, A. F. Rogers, T. L. Walker, H. S. Washington, and E. T. Wherry.

PRESENTATION OF PAPERS

With the exception of the presidential address by Doctor Wherry, which has been mentioned previously, the presentation of scientific papers was then taken up as follows, according to the program:

CRYSTALLOGRAPHIC NOTES ON PYRITE AND FLUORITE

BY A. C. HAWKINS

CRYSTALLOGRAPHIC-OPTICAL OBSERVATIONS ON STRYCHNINE SULPHATE

BY LEWIS S. RAMSDELL

FRIEDEL'S LAW OF RATIONALITY OF SYMMETRIC INTERCEPTS

BY AUSTIN F. ROGERS

DETERMINATION OF OPAQUE ORE MINERALS BY X-RAY DIFFRACTION PATTERNS

BY PAUL F. KERR

CHAPMANITE, A NEW MINERAL FROM SOUTH LORRAINE, ONTARIO

BY T. L. WALKER

COBALT NICKEL ARSENIDES FROM COBALT, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

MINERALOGRAPHIC STUDY OF GERMANITE, A GERMANIUM MINERAL FROM SOUTHWEST AFRICA

BY ELLIS THOMSON

KEMPITE, A NEW MANGANESE MINERAL FROM CALIFORNIA

BY AUSTIN F. ROGERS

WARDITE AND SOME OTHER ALTERATION PRODUCTS OF VARISCITE FROM UTAH

BY ESPER S. LARSEN AND EARL V. SHANNON

APPARENT NON-EXISTENCE OF CARNOTITE AND REMINGTONITE

BY EARL V. SHANNON

ANDALUSITE, A NEW USE AND SOME THERMAL PROPERTIES

BY A. B. PECK

CAUSE OF COLOR IN ROSE QUARTZ, A SUMMARY

BY EDWARD T. HOLDEN

CHEMICAL COMPOSITION OF COLLOPHANE

BY AUSTIN F. ROGERS

SOME UNUSUAL SPECIMENS OF FLOAT COPPER

BY EDWARD H. KRAUS

THOMSONITE FROM PEEKSKILL, NEW YORK

BY ALEXANDER H. PHILLIPS

PECTOLITE AND APOPHYLLITE FROM THETFORD MINES, QUEBEC, CANADA

BY A. L. PARSONS

HOEGBOMITE FROM VIRGINIA

BY THOMAS L. WATSON

CHRYSOBERYL PEGMATITE OF HARTFORD, MAINE

BY CHARLES PALACHE

PRELIMINARY DESCRIPTION OF THE GRANITE PEGMATITE AT BENNET'S QUARRY, WEST BUCKFIELD, MAINE

BY CHARLES PALACHE

REACTION OF CUPRIC SALTS IN IGNEOUS SOLUTION ON CHALCOCITE ABOVE 200 DEGREES

BY R. C. WELLS

MINERALS OF OBSIDIAN CLIFF AND THEIR ORIGIN

BY W. F. FOSHAG

ASSAYING WITH THE BLOWPIPE

BY W. F. HUNT

VARISCITE, PEGANITE, AND LUCINITE

BY ESPER S. LARSEN AND W. T. SCHALLER

ADVANTAGES OF OBLIQUE ILLUMINATION IN MINERAGRAPHY

BY W. M. MEYERS

AN UNUSUAL OCCURRENCE OF CYANITE

BY R. C. WALLACE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GRAVITY OBSERVATIONS FROM THE STANDPOINT OF THE LOCAL GEOLOGY [1]

PRESIDENTIAL ADDRESS BY DAVID WHITE

(*Read before the Society December 27, 1923*)

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[1] Manuscript received by the Secretary of the Society February 4, 1924.

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Introduction

Since the work of systematically measuring the gravity in all parts of the United States was, about 30 years ago, undertaken by the United States Coast and Geodetic Survey, over 325 stations have been occupied. The results of the observations at some of these stations were published in reports by Hayford and Bowie[2] in 1912, by Bowie[3] in 1912, and by Bowie[4] in 1917, when 219 stations, including those previously covered, were considered. Observations at 85 additional stations are in process of publication by Major Bowie in a report of the Coast and Geodetic Survey now in press. References to the literature on gravity observations will be found in Bowie's 1912 paper. The 1909 and 1910 papers by Hayford are based on the observations of deflections of the vertical as corrected for topography and isostatic compensation in the United States, whereas the reports by Hayford and Bowie and by Bowie are largely concerned with the effects of topography and isostatic compensation on the intensity of gravity at the stations, including many in foreign countries.

The gravity stations in the United States are reasonably well scattered, with, however, some concentration in several areas of unusual interest. The published results have been given more widespread attention by geodesists and geophysicists than by geologists. Few of the latter have examined the observations, even in general, much less in detail, and the consequent discussions relate mainly to the broad questions of the validity of the theory of isostasy, mountain-building, the rigidity of the earth's crust, depth to compensation, and the relative merits of the equational factors in the complex formulæ.

[2] Effect of topography and isostatic compensation upon the intensity of gravity. U. S. Coast and Geodetic Survey Special Pub. No. 10, 1912.

[3] Effect of topography and isostatic compensation upon the intensity of gravity (second paper). U. S. Coast and Geodetic Survey Special Pub. No. 12, 1912.

[4] Investigations of gravity and isostasy. U. S. Coast and Geodetic Survey Special Pub. No. 40, 1917 (printed January, 1917).

The interest of the writer dates from the publication of the joint paper, Special Publication Number 10 of the Coast and Geodetic Survey, as the result of which he was at once impressed with the close correspondence between the prevalence of plus anomalies and positive areas on the one hand and between minus anomalies and areas of deep subsidence (negative) and of consequent thick sedimentary deposits on the other. It is in fact emphasized in this paper that to a degree the anomalies may be compensated by departures of surface or near-surface rocks from average density, Cenozoic rocks being generally light and pre-Cambrian dense.

The thanks of the writer are due to Messrs. Hayford and Bowie, as well as to his colleagues and many friends who have generously assisted him in gathering the data used in the following pages.

Theoretical and measured Gravities

Calculation of theoretical gravity

To refresh the reader's memory as to gravity anomalies, it may be mentioned that gravity at any station is both calculated and measured. The reader will recall that in calculating the theoretical gravity at any point on the surface of the earth, gravity at sealevel at the equator is taken as the primary basis. This is derived from long series of observations for the absolute values of gravity at certain base stations, and the observations at many field stations by the relative method. The initial gravity quantity is compensated for latitude as on an ellipsoid of revolution; for elevation above the sea; for topography in blocks increasing successively in width outward and reaching around the world, the average density of the rocks above the sea being assumed to be 2.67 and of the ocean 1.028; and for compensation which, according to theory, makes all columnar sections of rock above the "depth of compensation," the "isopiestic depth" [5] of Henry S. Washington, to be of equal weight and entirely in balance, if the isostatic adjustment is ideally complete.

Sources of error in the calculation of theoretical gravity at any point

The calculated values of gravity are subject to some error, both as the result of the initial assumptions and as the result of the methods employed. Minor errors may lie in the formula for gravity at sealevel, and there would be serious errors if the elevations of the stations were not accurately known. Errors may result from inaccurate knowledge of the

[5] Isostasy and rock density. Bull. Geol. Soc. America, vol. 33, 1922, p. 402.

forms and volumes, as well as positions, of the topographic features, especially those near the station. The greater errors are due, however, (1) to lack of knowledge as to the actual rock densities near the gravity stations and especially below sealevel; (2) to the further assumption that the density of the aggregate rocks of the crust for any layer is the same all around the earth, except as modified by the isostatic compensation, and (3) to the additional assumption that compensation and isostatic equilibrium are everywhere complete at this "depth of compensation," which for the gravity reductions is taken as 113.7 kilometers.

It has, however, been pointed out by Gilbert[6] and Barrell,[7] and is accepted by the geodesists, that the depth of compensation may not be, and probably is not, at the same distance below tide level in all regions. Bowie holds that the computed depth of compensation is somewhat above the actual level of equal pressures; also, it is apprehended that the columnar sections at many points are lighter than at others and may be balanced and sustained in position by compensating rock-masses in adjacent or neighboring areas. On the whole, it seems probable, however, that in most regions the greatest sources of error—the greater number of the apparent departures from the normal—are due, as I hope to show, to variation in the density of the rocks under the instrument, to the structure of the rocks, and to their relations to the topography.

GRAVITY ANOMALIES DEFINED

Gravity anomalies are the differences between the theoretical gravity as calculated for any station and the gravity as actually measured. Excess of measured gravity over theoretical is *plus;* deficiency is *minus.* Overloaded areas should show plus anomalies; abnormally light show minus.

INFLUENCE OF ROCKS AT OR NEAR THE SURFACE ON THE AMOUNT AND SIGN OF THE ANOMALY

It has been emphasized by the geodesists,[8] though it has not been taken into account in the computations, that the presence of rocks of excessive or of deficient density near any station may cause a notable variation in the measured gravity. When the abnormally light or heavy rocks lie directly beneath the instrument and near the surface, the effect for any

[6] Interpretation of anomalies of gravity. U. S. Geol. Survey Prof. Paper 85, 1913, p. 29.

[7] The strength of the earth's crust. Journal of Geology, vol. 22, 1914, p. 209.

[8] Sp. Pub. No. 40, U. S. Coast and Geodetic Survey, p. 70 et seq.; also, Some geological conclusions from geodetic data, by W. Bowie, Proc. Nat. Acad. Sciences, January, 1921.

given mass is much greater than when the material is deep-seated or off to the side. The inverse of the square of the distance between the center of mass and the station enters into the calculation of the effect. Obviously the more widely the rock departs in weight (density) from the normal, and the greater its thickness, the greater is its influence, which is multiplied in increasing terms as it approaches the pendulum at the surface of the ground. Horizontal extension of the strata beyond the dominance of the vertical component diminishes this effect. Deep but relatively narrow synclines, or fault blocks, of light rocks close beneath the instrument should and, other things being equal, do give large minus anomalies, while, conversely, bosses, fault blocks, great intrusive masses, or axial mountain cores of matter heavier than the average, or of rock under which heavy mineral matter is comparatively shallowly buried, should and do cause plus anomalies, as will be seen. The heavier or the lighter, the greater the anomaly. Heavy rock at the surface may diminish, conceal, or even preponderate over the effects of underlying light strata of greater thickness, or contrary relations and effects may obtain. It follows that compensation for departures in density from the assumed normal in the terranes within a few thousand feet beneath the pendulum will in cases wipe out the anomaly or even establish an anomaly of the opposite sign, thus reversing the superficially apparent significance of the anomaly. The fact that anomalies may so be liquidated or reversed proves not only how nearly the earth's crust approximates equilibrium, but it also indicates a nearer approximation to balance in most regions and in general than would appear from the inspection of the gravity anomaly map. The variety and intricacy of the relations of local rock density, stratigraphy, and structure to the results of gravity calculation on the one hand and the measured gravity on the other can be conceived only by the geologist. The effects may be everywhere complex, but in many areas the dominant features may be recognized and reasonably interpreted.

Barrell,[9] recalling the great variation of densities even in rocks of the same type, has pointed out the prevalence of minus anomalies in the great synclines and regions of great thickness of unconsolidated strata, and of plus anomalies in metamorphic areas, and Bowie[10] has emphasized and illustrated the predominant effect of light rocks in the Cenozoic, as, for example, the Atlantic Coastal Plain, and the generally plus anomalies in regions of pre-Cambrian, Paleozoic, and Mesozoic formations. Hobbs[11]

[9] Op. cit., pp. 210-226.

[10] U. S. Coast and Geodetic Survey Special Pub. No. 40, p. 78.

[11] Assumptions involved in the doctrine of isostatic compensation, with a note on Hecker's determination of gravity at sea. Jour. Geology, vol. 24, 1916, pp. 668 and 704.

emphasizes consideration of variant densities in the upper part of the earth's crust, and Sir S. G. Burrard[12] directs attention to the great thickness of light sediments as affecting the anomalies of the Gangetic plain. Gilbert[13] early put geodesists on guard against such effects, and recently, before this Society, Lane[14] has insisted that apparent evidence of lack of balance may result merely from densities of surface rocks. It is, however, greatly to be regretted that no American geologist has studied the individual gravity anomalies with special reference to the local geological formations, their stratigraphy, thickness, structure, and, of course, their density. Such geologic analysis and its study in conjunction with similar analyses pertaining to other points, station by station, are indispensably prerequisite, both to the determination of the significance and approximate value of any given anomaly and to any conclusion as to the isostatic situation in any region.

GENERALLY MEAGER LOCAL GEOLOGIC DATA

At many stations the geologic criteria necessary for the satisfactory interpretation of the respective anomalies are unknown or even unascertainable, at least at the present. For many others the ascertainable facts are, unhappily, most meager, while at no point is the information so complete as is desired. Further, no single geologist is in command of all the available information relating to all the stations occupied. On the other hand, many of the stations were occupied without regard to local geologic conditions, not to mention the question of essential pertinent geologic knowledge thereof in advance. Nevertheless, much may at the present moment be developed respecting both the value and significance of the anomalies, on the one hand, and the subsequent questions of overloading or underloading in different regions of the country, on the other.

DENSITIES AND SPECIFIC GRAVITIES OF ROCKS

When one begins to compile the available data as to the densities of the different types of rock—more particularly sediments of varying stages of compactness or alteration—he is inevitably impressed with the painful lack not only of sufficient criteria on the whole, but of standardization of methods and results. In many cases doubt remains as to whether "specific gravity" relates to the pulverized rock and the mineral constituents or the

[12] Investigations of isostasy in Himalayan and neighboring regions. Survey of India, Professional Paper No. 17. 1918. pp. 2-7.

[13] Notes on the gravity determinations reported by Mr. G. R. Putnam. Bull. Philosophical Society of Washington. vol. 13. 1895, pp. 61-65.

[14] Weight of sedimentary rocks per unit volume. Bull. Geol. Soc. America, vol. 33, 1922, pp. 367-368.

weight of the rock-mass. "Density" and "specific gravity" in some statements appear to be interchangeable. The lack of uniformity in method of determining specific gravity and density employed in the different laboratories and the obvious lack of standardization in results reminds him of the chaotic state of fuel analyses before the laboratory processes were standardized by the American Chemical Society.

Data, whether in terms of density or specific gravity, relating to igneous rocks, are none too abundant and are in too many cases either generalized or averaged. Further, more attention has been given by petrologists and rock chemists to the altered and highly "mineralized" or metalliferous igneous and metamorphic rocks than to the normal matter which forms the greater portion of the rock-masses, but is of less interest to the economic geologist and student of ore genesis.

With sedimentary formations, however, the case is much worse, not only on account of gross insufficiency of information, but on account of unreliability or ambiguity of the published criteria. There are comparatively few publications in which extensive density and specific gravity determinations of sediments of different types, made in accordance with approved methods, described therewith, are available. Among these is the report on the natural building stones and roof shales of Switzerland, issued in 1915 by the Geological Survey of Switzerland,[15] and an interesting and constructive discussion given by Arthur Holmes in the first part of his "Petrographic Methods and Calculations."

Most American geologists are familiar with the works by Merrill,[16] Buckley,[17] Ries,[18] Hirschwald,[19] and others on building stones, clays, and other sediments, and the widespread information as to specific gravities or densities of igneous rocks in papers by Rosenbusch,[20] Washington,[21] Pirsson,[22] Iddings,[23] and other petrologists. Averages of group types have been compiled by Barrell[24] and Daly.[25]

Merely as an aid to the reader in the rough calculation of rock density

[15] Die natürlichen Bausteine und Dachschiefer der Schweitz. Beiträge zur Geologie der Schweiz, Geotechnische Serie V. Lieferung. II. Petrographisch-technologischer Teil, U. Grubenmann, A. Erni, F. Schüle, und B. Zschokke. Bern, 1915.

[16] George P. Merrill: Stones for building and decoration. 1891.

[17] E. R. Buckley: Building and ornamental stones of Wisconsin. Wisconsin Geological and Natural History Survey Bull. No. IV. Economic Series No. 2. 1898.

[18] Heinrich Ries: Clay deposits and clay industry in North Carolina. North Carolina Geol. Survey Bull. No. 13. 1897.

[19] J. Hirschwald: Handbuch der bautechnischen Gesteinsprüfung, p. 105. Berlin, 1912.

[20] H. Rosenbusch: Elemente der Gesteinslehre, p. 292. Stuttgart, 1901.

[21] H. S. Washington: U. S. Geol. Survey Prof. Paper 99, 1917, pp. 168-169.

[22] L. V. Pirsson: Rocks and rock minerals. 1908.

[23] Joseph P. Iddings: Igneous rocks, vol. I, 1909; vol. II, 1913.

[24] Joseph Barrell: The strength of the earth's crust. Jour. Geology, vol. 22, 1914.

[25] R. A. Daly: Igneous rocks and their origin, 1914, p. 202.

Densities and specific Gravities of sedimentary Rocks

(Specific gravities are indicated by the asterisk)

1. *Argillaceous*

Silt, bottom Hudson River channel	1.25 1.28
Silt, 40-50 feet below Hudson River channel	1.66–1.8
Common mud, packed wet	1.68
Piedmont *residual clays* Average, 2.47±	2.24–2.63
Glacial clay	2.08
Colorado Springs, Colorado, surface	2.19
Atlantic *Cretaceous clay* (commercial) Average, 2.47±	2.30–2.68
Loess, four samples, Kansas Average, 1.83.	1.75–1.95
Shales, Pierre, Colorado	2.41
Coal Measures, Missouri	2.49
Cincinnati, Ohio	2.45
Cleveland, Ohio (gray)	2.46
Cleveland, Ohio (black)	2.44
Average, four Paleozoic	2.46
Supai, Grand Canyon (ferruginous)	2.63
Bright Angel, Arizona	2.51
Hermit shale (red)	2.49
Catskill, Maryland (red)	2.53
(2) Catskill, Maryland (ferruginous)	2.72
Catskill, Maryland (more iron)	2.75
Argillite (Daly)	2.40–2.8
Slates:	
Six commercial slates, Maine, New York, Vermont, and Minnesota Average, 2.78.	2.71–2.83
Schists (Daly)	2.60–2.75

2. *Sands and Sandstones*

Dry sand, with light minerals	1.30
Wet sand with heavy minerals Average dry, 1.55; average wet, 1.96.	2.36
Sands, two, Colorado Springs, Colorado	1.90 1.82
Colorado City, Colorado, arkosic	1.99
Chicago, Illinois Campus	2.00
Terre Haute, Indiana	1.96
Terre Haute, Indiana gravel and hardpan	1.98
Dakota sandstone, Kansas residual	1.98
New Jersey Cretaceous	2.24
Sandstones:	
Sixteen Swiss, Tertiary and Triasic, mostly friable, 16 per cent to 20 per cent porosity Average, 2.18.	2.09–2.24
Denver, Colorado, Tertiary, friable	2.00
Four Dakota sandstone, Kansas, and Colorado Average, 2.33.	2.28–2.37
New Mexico, Cretaceous	2.29
*22, Colorado, Utah, and Wyoming Average, 2.24.	1.95–2.52
Three Triasic, Maryland	2.31–2.49
*22, Michigan, Minnesota, and Wisconsin Average, 2.21.	1.82–2.85
*26, Connecticut, New York, New Jersey, Missouri, and Ohio Average, 2.28.	2.11–2.42
Seven Paleozoic, Pennsylvania, New York, Kansas, Tennessee, and Arizona Average, 2.54.	2.32–2.69

Average, 2.78.
Schists (Daly) 2.60–2.75

Tennessee, and Arizona .....
Average, 2.54.

Densities and specific Gravities of sedimentary Rocks—Continued

1. *Argillaceous*	
Quartzites:	
Four, Pennsylvania, New York, Tennessee	2.52–2.69
Average, 2.61.	
Conglomerates:	
Quartz porphyry breccia	2.63
Quartz breccia	2.72
Eocene limestone conglomerate	2.70
Fine-grained calcareous conglomerate	2.74
Tuff:	
Rhyolite tuff, Colorado	2.19
Tuff, California	2.32

2. *Sands and Sandstones*	
Sandstones:	
84 Swiss, *all kinds; average*	2.45
Coconino, Grand Canyon, Arizona	2.31
Tapeats, Grand Canyon, Arizona	2.46
Southern Arizona	2.66
North Mountain, Maryland, Tuscarora	2.56
Berkeley Springs, West Virginia, Oriskany	2.51
Catskill, Maryland (ferriferous)	2.73
24 Swiss, of heavier types	2.26–2.65
Average, 2.35.	
24 Swiss of heavier types	2.26–2.65
Average, 2.47.	
12 Swiss arkosic	2.29–2.64
Average, 2.43.	
32 Swiss calcareous	2.44–2.73
Average, 2.59.	
18 Miscellaneous European	2.29

UM

compensation of some of the anomalies given later in this paper, I introduce the preceding table, very incomplete, of sandy and argillaceous sediments, which is based mainly on data condensed from the Swiss report and on determinations made many years ago for Stose and Gilbert and more recently for the writer in the laboratory of the United States Geological Survey.

In the application of density or specific gravity data, the geologist needs possibly to be reminded to give heed to the stage of compression or incipient alteration of the sediments, especially when dealing with the silts and argillaceous types. The compression produced by horizontal stresses acting differentially on such sediments through long periods is enormously greater than that resulting from loading, which merely presses the rock material downward. The results of exploration for oil in different regions and the study of the cuttings show that throughout great areas, at least, the sediments are not gorged with water; sometimes they are but partially occupied by it, pore space and voids being shared by petroleum or by hydrocarbon and other gases.[26] Regard is to be had also for the voids existing, even in igneous rocks, as shown by Schüle in the Swiss report above cited and by Hirschwald. The difference between mineral specific gravity and mass density[27] of most igneous rocks seems to approximate .10.

EMPIRICAL VALUES OF DENSITY UNITS

The accompanying table, page 217, of values of unit density at different depths and within 7½ miles of the station is introduced through the courtesy of Major Bowie. A more extended presentation of the mathematical criteria, with instructions for its application under rather complex conditions, is given in his paper now in press.

ANOMALIES USED IN THIS PAPER

The anomalies, placed in correspondence to the geographic locations of the stations, in the United States east of the 110th meridian, are shown in Plate 6. They are based on the Hayford 1912 formula, in which the depth of isostatic compensation is put at 113.7 kilometers (approximately 70 miles). They are known as the "1912 Isostatic

[26] Calculations of saturated and unsaturated igneous rocks are given by Washington[28] and by Barrell,[29] who, following Fuller, would regard the pore space of sediments as half filled with water.

[27] In this connection see L. H. Adams and E. D. Williamson: The compressibility of minerals and rocks at high pressures. Journ. Franklin Inst., vol. 195, 1923, pp. 475-529.

[28] H. S. Washington: Isostasy and rock density. Bull. Geol. Soc. America, vol. 33, pt. 2, June 30, 1922, pp. 375-410.

[29] Joseph Barrell: Op. cit., p. 214.

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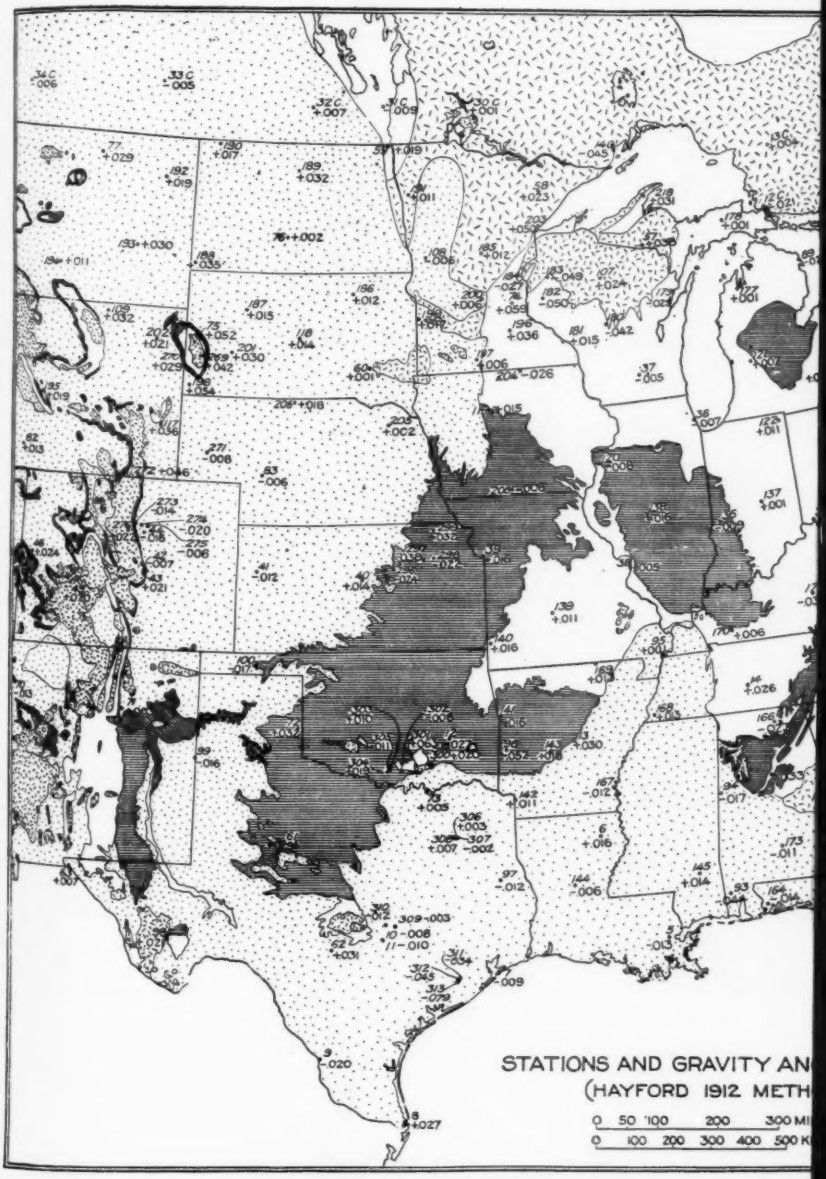
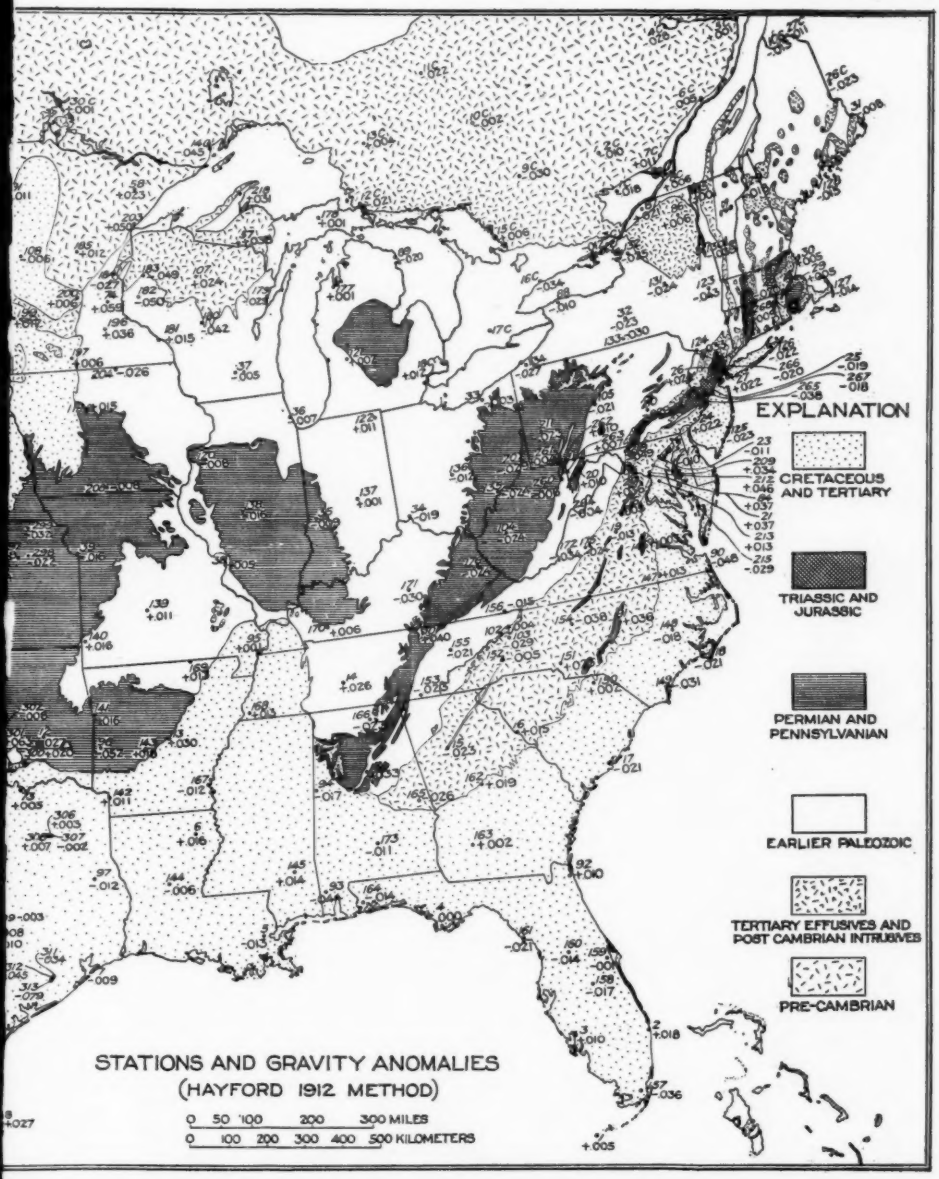


GEOLOGICAL SKETCH MAP OF THE UNITED STATES EAST O

Showing the distribution of gravity stations, with special reference to areas of expos ed



ETCH MAP OF THE UNITED STATES EAST OF THE ROCKY MOUNTAINS

ions, with special reference to areas of exposed pre-Cambrian rocks and upper Paleozoic synclines.

Attraction of cylindrical Blocks

[Station at center of upper surface. Density = 1]

Depth of block	Radius of block in miles														
	½	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½
Feet	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne	Dyne
1,000..	.010	.012	.012	.012	.012	.012	.012	.012	.013	.013	.013	.013	.013	.013	.013
2,000..	.017	.021	.022	.023	.024	.024	.024	.025	.025	.025	.025	.025	.025	.025	.025
3,000..	.021	.028	.031	.033	.034	.035	.035	.036	.036	.036	.036	.037	.037	.037	.037
4,000..	.024	.034	.039	.042	.044	.045	.046	.046	.047	.047	.048	.048	.048	.048	.049
5,000..	.025	.038	.045	.050	.052	.054	.055	.056	.057	.058	.058	.059	.059	.060	.060
6,000..	.027	.042	.051	.056	.060	.062	.064	.066	.067	.068	.069	.070	.070	.071	.071
7,000..	.028	.045	.056	.063	.067	.071	.073	.075	.077	.078	.079	.080	.080	.081	.082
8,000..	.028	.047	.060	.068	.074	.078	.081	.084	.086	.087	.088	.090	.091	.091	.092
9,000..	.029	.049	.063	.073	.080	.085	.089	.092	.094	.096	.098	.099	.100	.101	.102
10,000..	.029	.051	.066	.077	.085	.091	.095	.099	.102	.104	.106	.108	.110	.111	.112
12,000..	.030	.053	.071	.084	.094	.102	.108	.113	.117	.120	.123	.125	.127	.129	.130
14,000..	.031	.055	.075	.090	.102	.111	.119	.125	.130	.134	.138	.141	.144	.146	.148
16,000..	.031	.057	.078	.094	.108	.119	.128	.135	.142	.147	.152	.156	.159	.162	.165
18,000..	.031	.058	.080	.098	.113	.126	.136	.145	.153	.159	.165	.169	.173	.177	.180
20,000..	.032	.059	.082	.102	.118	.132	.144	.154	.162	.170	.176	.182	.187	.191	.195
25,000..	.032	.060	.086	.108	.126	.143	.158	.170	.182	.191	.200	.208	.215	.221	.226
30,000..	.032	.062	.088	.112	.133	.152	.169	.184	.198	.210	.221	.231	.239	.247	.255

$$\text{Attraction} = 2\pi\kappa\delta\,(c + t - \sqrt{c^2 + t^2})$$

$\kappa = 6673\ (10^{-11})$

$\delta = 1$ (in this table)

$2\pi\kappa\delta = .4193\ (10^{-8})$

$\log.\ 2\pi\kappa\delta = 3.62250 - 10$

Anomalies." It will, however, be recalled that the reduction of the residuals for the anomalies at mountain stations is more nearly complete when the calculation is based on an assumed compensation at depth of 96 kilometers, in accordance with the Bowie formula, as set forth in Special Publication 40 of the Coast and Geodetic Survey.

After discussing the density and weight of the outer crust in different continents and portions of some of the continents, as calculated from the chemical averages of the igneous rocks, Washington arrives at a probable density of 2.792 as the average of the earth's crust, calculated on a water-free basis, or 2.737 if allowance is made for 1 per cent of "water on ignition." [30]

In the tables of gravity anomalies shown on later pages are given the 1912 isostatic anomalies, in which the depth of compensation is uniformly taken to be 113.7 kilometers below sealevel. These are known as the Hayford anomalies. Following these in each case are for comparison given (2) the anomalies as calculated by the Bowie formula, with depth of compensation of 60 kilometers, and (3) the anomalies according to the Helmert formula, the depth of compensation being 113.7 kilometers. All are taken from Special Publication 40, except the statements for groups of unpublished stations which bear numbers greater than 219, which will be found in Special Publication 99.

In this most superficial and incomplete review, which was begun immediately following the publication of Bowie's report, early in 1917, but for lack of time postponed until the present winter, I shall have little to say concerning isostasy as a principle, or the causes of mountain-building, or of folding as a process.[31] Further and more thorough analyses by the competent dynamic geologist, aided by the stratigrapher, will give succinctness to such a discussion, if indeed they are not prerequisite to it.

Discussion of the Hayford Anomalies

Atlantic coastal plain north of Florida

The Atlantic Coastal Plain lies well within the continental shelf and may, for present purposes, be regarded as a portion, including the west-

[30] Bull. Geol. Soc. America, vol. 30, 1922, p. 390.

[31] Among the voluminous literature relating to isostasy as affecting mountain-building, etcetera, mention in particular may be made of the following: T. C. Chamberlin, Jones's criticism of Chamberlin's groundwork for the study of megadiastrophism: Am. Jour. Sci., vol. iv, October, 1922, pp. 253-273; Diastrophism and the formative processes. XIV. Groundwork for the study of megadiastrophism: Part I. Summary statement of the groundwork already laid, T. C. Chamberlin; Part II, The intimations of shell deformation, R. T. Chamberlin: Jour. Geology, vol. xxix, no. 5, July-August, 1921, pp. 291-425; and Diastrophism and the formative processes. XV. The self-compression of the earth as a problem of energy: T. C. Chamberlin, Jour. Geology, vol. xxix, no. 8, Novem-

ern half, of a basin or trough. Sands, sandy clays, marls, gravels, clays, and diatomaceous earth, mostly uncemented and unconsolidated, with a few thin limestones, composing the Cretaceous, Tertiary, and Pleistocene deposits, slope gently toward the coastline where, in some areas, their thickness probably exceeds 2,500 feet. The deposits have been subjected to relatively little horizontal thrusting or deformation, and consequently have suffered little compression or dehydration other than by vertical loading and by draining. The basal deposits are nearly as light as those near the top and carry water. Pleistocene and alluvial sediments of very light material are thin, even in the estuaries and near the ocean border. The limestone is richly fossiliferous and more or less porous and its total is comparatively insignificant.[32] The clays range from 1.8 to 2.6 in density, and the average density of the aggregate deposits of the Coastal Plain region may not exceed 2.28. The sediments vary in character from place to place, but with respect to lightness the section is perhaps surpassed only by the Pleistocene and Tertiary deposits of the Texas-Louisiana Gulf coast. Much greater thicknesses of exceptionally light rocks are exposed in the Tertiary areas of southern California, the Puget basin of western Washington, and probably in some of the lake deposits, agglomerates, and washes of the Great Basin and northwestern regions.

The igneous and metamorphic floor of the Coastal Plain section is continuous with the Piedmont region. It should contain similar rocks that must vary in structure and composition more or less like the eastern border of the Piedmont, where heavy pre-Cambrian intrusives are seen to strike somewhat southerly beneath Cretaceous or Tertiary cover, rather than always parallel to the Appalachian structure. Some of these con-

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ber-December, 1921, pp. 679-700; Joseph Barrell, The strength of the earth's crust: Jour. Geology, vol. 22, nos. 1-8, 1914, and vol. 23, nos. 1, 5, 6, 1915; W. H. Hobbs, Assumptions involved in the doctrine of isostatic compensation, with a note on Hecker's determination of gravity at sea: Jour. Geology, vol. xxiv, no. 7, October, November, 1916, pp. 690-717; R. A. Daly, The earth's crust and its stability: Am. Jour. Sci., vol. v, May, 1923, pp. 349-372, and Decrease of the earth's rotational velocity and its geological effects: Am. Jour. Sci., vol. v, May, 1923, pp. 372-377; R. T. Chamberlin and F. P. Shepard, Some experiments in folding: Jour. Geology, vol. xxxi, no. 6, September-October, 1923, pp. 490-512; and the papers and discussions in the symposium on isostasy, reported in vol. 3, no. 2, of the Bulletin of the Geological Society of America, 1923. Also W. W. Bowie, Some geological conclusions from geodetic data: Proc. Nat. Acad. Sciences, January, 1921; The relation of isostasy to uplift and subsidence: Am. Jour. Science, July, 1921; Yielding of the earth's crust: Ann. Rept. Smithsonian Inst., 1921; The earth's crust and isostasy: Geographical Review, October, 1922.

[32] The Atlantic Coastal Plain as a whole is shown on the map of North America accompanying U. S. Geol. Survey Prof. Paper 71; see also U. S. Geol. Survey Bull. 597; Prof. Paper 82; New Jersey State Geological Survey geological map of New Jersey; U. S. Geol. Survey Water Supply Paper 110 and Bull. 138; Virginia Geol. Survey Bull. 5; U. S. Geol. Survey Water Supply Papers 369, 341, and 364 and Prof. Papers 120-C, 90-J, and 90-H; also reports of Maryland Geol. Survey and U. S. Geol. Survey Geol. Atlas, Folios Nos. 23, 80, 136, 137, 152, 182, 204, and 211.

cealed variations must affect strongly the anomalies and might be roughly defined by the latter if the stations were sufficiently numerous. A barrier, west of which the fresh-water deposits of the basal Cretaceous were laid down, is presumed to be present this side of the continental border, but on the whole the basement floor is believed to be relatively even, though more than one peneplain may lie concealed, and Triassic, if not older, basins are buried within the area. Wells reaching bedrock near the coast report "granite."

In his discussion of the anomalies with reference to the geologic formations in different parts of the United States, Major Bowie[33] shows that a large proportion of the stations in the Cenozoic have the minus sign. This is especially evident in the Atlantic Coastal Plain.

It will be observed on referring to the accompanying table[34] (A) that all but one among the anomalies in the Atlantic Coastal Plain deposits north of Florida show a minus sign, the anomaly being, in general, greater in amount over the thicker deposits near the coastline and smaller farther inland. The single exception, Upper Marlboro, Maryland, 15 miles east of Washington, is in strike with the gabbro belt outcropping at Laurel, and it is more than possible that the moderate size of the plus anomaly, .013, at this point, where the Coastal Plain section is supposed to exceed 1,500 feet, is due to that fact. Gravity observation at additional stations will almost certainly disclose other heavy spots, but the proportion of minus anomalies may be expected to remain nearly the same.

TABLE A

Atlantic Coastal Plain North of Florida

I. OUTER ZONE

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
127	Chatham, Mass.....	—.014 —.007 —.006	Pleistocene sands on Tertiary (or Cretaceous). No wells to hard rock.
126	Bridgehampton, N. Y...	—.022 —.016 —.014	Pleistocene sands and clays on deep (1,000+) Cretaceous sands and clay, etcetera.

[33] W. W. Bowie: U. S. Coast and Geodetic Survey Special Pub. 40, p. 76, 1917. Some relations between gravity anomalies and the geologic formations in the United States. Am. Jour. Sci. (4th ser.), vol. 30, 1912, p. 237.

[34] The comments and the formational data in the right-hand column of the table and the accompanying suggestions, by way of explanation of the anomalies, represent necessarily incomplete information. In many cases, in fact, the data may be erroneous, while far weightier criteria known to other geologists are omitted. Corrections for this or the following tables will be heartily welcomed.

TABLE A—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
125	Atlantic City, N. J.	—.023 —.018 —.015	Sands, marls, clay, gravels of Pleistocene, Tertiary, and Cretaceous; well in Lower Cretaceous at 2,200.
215	Crisfield, Md.	—.029 —.023 —.021	Sands, gravels, marls, clays and thin limestones of Pleistocene, Tertiary, and Cretaceous. Well in Tertiary at 1,706 feet on Isle of Wight; in Cretaceous at 2,300 feet.
90	Virginia Beach, Va.	—.048 —.039 —.040	Alluvium, sands, gravel, clay, marls, and a few thin limestones. Thick Pleistocene, Tertiary and Cretaceous; 2,240 to crystalline at Fort Monroe.
18	Beaufort, N. C.	—.021 —.008 —.013	Pleistocene on Tertiary and Cretaceous, mostly unconsolidated; thickness unknown.
149	Wilmington, N. C.	—.031 —.024 —.023	Sands, clay, etcetera, of Pleistocene and Cretaceous. "Granite" reported at 1,109 feet. Error in report, or light light rocks probably in sub-cretaceous floor?
17	Charleston, S. C.	—.021 —.016 —.013	Pleistocene, thin Tertitary, and Cretaceous; well in Eutaw at 2,007.

II. MIDDLE ZONE

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
217	Dover, Del.	—.010 —.006 —.002	Pleistocene, Tertiary, and Cretaceous sands, marls, clays, gravel, etcetera, at 1,200+.
148	Greenville, N. C.	—.018 —.012 —.010	Pleistocene, Tertiary (?), and Cretaceous clays, sands, gravel, marls, and thin limestones; no deep wells; possibly buried Triassic.
213	Upper Marlboro, Md.	+.013 +.016 +.021	Normal sediments of Coastal Plain, very thin limestones in well 1,500. Station in strike with gabbro belt of Laurel.

The influence of the light weight of the sediments of the Coastal Plain in increasing, where not actually causing, this remarkable series of minus anomalies, can not be doubted. The effect of the abnormally light rocks is particularly great, since most of them lie below sealevel. Yet the size of most of these anomalies far exceeds the allowances normally sanctioned for aggregates of so little thickness as 3,000 feet, even where the matter has a density of but 2.3 instead of 2.67. A compensation of .010 to .012 for

deficiency of weight at any of these stations is probably excessive. On the other hand, however, if rocks of the average Piedmont type are present immediately beneath the deposits of the Coastal Plain, a consequent excess density, causing, as we shall see, a rather large average plus anomaly, is to be overcome before a minus sign is possible. Therefore, although nothing at the eastern border of the Piedmont indicates for the floor of the Atlantic Coastal Plain pre-Cambrian rocks lighter than the heavy material west of the "Fall Line," unless buried Triassic or Paleozoic basins are present, we must conclude that the rocks in the sub-Cretaceous floor are actually lighter than those of the exposed Piedmont. Since Triassic or older sediments can not be present at all the stations, it becomes probable that the very heavy matter near the surface in the Piedmont either does not lie beneath Coastal Plain stations other than Upper Marlboro or it lies very much deeper in the pre-Cambrian, which may not have been so deeply eroded. The alternative inference is that the Atlantic Coastal Plain area is underloaded. In the latter case the frequent vertical movements of this area both downward and upward during Pleistocene and Recent times can not be overlooked. According to evidence adduced by the late C. A. Davis, which I regard as reasonably conclusive, the coast of this region is now sinking. The tendency since early Cretaceous time toward subsidence in this extensive region is incompatible with absolute deficiency in weight of the rock column.

THE PIEDMONT REGION

General statement.—The structure and lithology of the Piedmont belt are as complex as its partially unraveled history. An Archean pattern is here and there masked or slashed by infolded or faulted and more or less altered Paleozoic and Proterozoic sediments and by pre-Cambrian as well as later batholiths and minor[35] intrusives. Triassic basins were superposed on its eroded surface and with it folded and infaulted. Granites and gneisses vary in composition and density, and metamorphism, increasing in general toward the east, varies in intensity. The Piedmont region has been the scene of many an ancient revolution and

[35] See U. S. Geol. Survey Geol. Atlas, Folio No. 83; New Jersey State geological map by J. Volney Lewis and Henry B. Kummel, edition 1918; U. S. Geol. Survey Geol. Atlas, Folio No. 162, Prof. Paper 98-b, and Bull. 28; Virginia Geol. Survey State geologic map; T. L. Watson, F. B. Laney, and George P. Merrill, The building and ornamental stones of North Carolina, North Carolina Geol. Survey Bull. No. 2, 1906; T. L. Watson, Granites and gneisses of Georgia, Georgia Geol. Survey Bull. No. 9-A, 1902; Nineteenth Ann. Rept., U. S. Geol. Survey, pt. 2, 1899; Bulletins 483 and 426, and Geol. Atlas, Folios Nos. 10, 13, 78, 90, 143, 116, 124, 147, 151, and 187. Unpublished information furnished by Charles P. Berkey, J. Volney Lewis, F. Bascom, Anna I. Jonas, T. L. Watson, Arthur Keith, J. H. Pratt, S. W. McCallie, Laurence La Forge, and G. W. Stose.

has been a mother source of sediments during cycle after cycle of sedimentation. Gold-bearing veins have been worn down to their roots. Hoisting and stripping have brought underlying heavier rocks nearer to the surface in portions of the Piedmont region than in most other areas of the continent. In all reason, therefore, the anomalies of the belt may be expected to vary according to the composition of the local underlying igneous and metamorphic rocks, the occurrence of infolded synclines of Paleozoic or Triassic sediments, and the mechanics of structure. They do.

"Fall Line."—As will be seen in Table B, the gravity anomalies along the "Fall Line," or eastern border of the Piedmont, are plus, indicating abnormally dense rocks, except at two stations. That unusually heavy rocks underlie the eastern portion, at least, of this region has been pointed out by Washington[36] and is locally indicated by gabbro and diorite intrusives.

TABLE B

Piedmont Crystalline and Metamorphic Regions

1. PIEDMONT "FALL LINE"

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations
162	Macon, Ga.	+.019	"Highly siliceous crystallines."
		+.021	
		+.027	
150	Cheraw, S. C.	+.002	Very thin Cretaceous sands and clays
		+.005	on pre-Cambrian.
		+.010	
147	Emporia, Va.	+.013	"Granite," sloping gradually under edge
		+.016	of Tertiary; gneiss, 2.68 specific
		+.021	gravity.
146	Richmond, Va.	+.003	Thin Tertiary and Cretaceous on
		+.005	"granite-gneiss." Light granite, 2.64
		+.011	specific gravity.
216	Fredericksburg, Va.	+.005	Thin Cretaceous on granite-gneiss, 2.68
		+.007	specific gravity.
		+.013	
21	Washington,, D. C.	+.037	(Coast and Geodetic Survey station.)
		+.038	Biotite granite, 2.73 specific gravity.
		+.045	
22	Washington, D. C.	+.039	(Smithsonian Institution Station.) Bio-
		+.040	tite granite, 2.73 specific gravity.
		+.047	
84	Washington, D. C.	+.037	(Bureau of Standards station.) Bio-
		+.039	tite-granite, 2.77 specific gravity.
		+.045	Zone between granite-gneiss and belt of hornblende and gabbro diorites.

[36] H. S. Washington: Isostasy and rock density. Bull. Geol. Soc. America, vol. 33, part 2, June 30, 1922.

TABLE B—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
209	Laurel, Md.	+.034 +.036 +.042	Baltimore gneiss, and gabbros, two miles from contact of Coastal Plain.
23	Baltimore, Md.	—.011 —.008 —.003	Baltimore gneiss near massive gabbros, veneered by Cretaceous; infolded synclines, rather thin pre-Cambrian quartzites and limestones, two to eight miles distant.
24	Philadelphia, Pa.	+.022 +.025 +.030	Wissahickon mica gneiss; density, 2.73 and 2.85.
267	Plainsboro, N. J.	—.018	Cretaceous surficial, probably on or near overthrust of pre-Cambrian rocks on Triassic, three miles southeast of Princeton.
25	Princeton, N. J.	—.019 —.016 —.011	2,300+ feet arkosic sandstone, conglomerate, brown sandstone, and shale, faulted (three miles east) under pre-Cambrian rocks.
27	New York, N. Y.	+.022 +.025 +.030	Belt Manhattan biotite schist, 2.77 specific gravity, in syncline altered Inwood limestone, 2.84 specific gravity, on Fordham gneiss, 2.77 specific gravity.
26	Hoboken, N. J.	+.024 +.027 +.032	Altered pyroxenite, with Triassic on west and metamorphics and crystallines on east.

The largest plus anomalies yet observed along the "Fall Line" are met in the vicinity of Washington, where the biotite granites, the dominant pre-Cambrian rocks of the vicinity, underlying the stations, are said to vary in density from 2.73 to 2.81. Diorites are not far away. Greater densities may, however, later be found in rocks underlying other points in this great region. Gabbroic intrusives are in evidence near Laurel[37] and occur in large masses near Baltimore, on account of which, the anomaly, —.011, at this station, located on Baltimore gneiss, is the more remarkable. The Baltimore anomaly is at present literally nonplussing. The explanation will very likely be found in the structure, for infolded and overthrusted pre-Cambrian quartzites and limestones are seen within three miles of the station.

Deep Triassic basin.—Princeton, one of the two stations with a minus anomaly, .019, though geographically in the Piedmont, lies three miles

[37] Fairfax, Virginia, Washington, and Laurel appear to lie in a zone of excess density, comagmatic, as pointed out by Dr. Henry Washington, toward which the deflection is strongly marked.

to the west of the faulted eastern border of the profoundly deep Triassic basin and is underlain by several thousand feet of arkosic sandstones, conglomerates, brown shales, etcetera, all of notably light weight. The structural and stratigraphic relations of the light Triassic sediments to the overthrust complex of the Piedmont appear to embrace the explanation of a large part at least of this minus anomaly.

To test this tentative conclusion two additional stations were, through the courtesy of the Coast and Geodetic Survey, established in 1918, as follows: Station 265, Pennington, New Jersey, seven miles west-southwest of Princeton, where the Triassic sandstones and shales, without flows or intrusives, should exceed 6,300 feet; Station 266, Glen Ridge, New Jersey, ten miles northwest of Hoboken, where the Triassic sandstones, shales and conglomerates should exceed 10,000 feet, with, however, the inclusion of 700 to 900 feet of trap at a probable depth of 8,000 feet below the surface. The estimates of the thickness of the Triassic in these regions are somewhat speculative, the eastern margin of the Triassic basin being overthrust by Piedmont rocks. Sediments of Paleozoic age may underlie portions of the Triassic area.

The anomaly for Pennington is —.038, .012 larger than that at Princeton; that for Glen Ridge, —.020. The latter approximates the deficiency in gravity of 8,000 feet of sediments having the estimated average density (2.49) of the Triassic in this region.

TABLE C

Piedmont, Interior, and West Border

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
163	Opelika, Ala.	—.026	Two infolded synclines, with quartzites within eight miles.
		—.020	
		—.017	
15	Atlanta, Ga.	—.023	Biotite gneisses and schists, with intrusive granitic masses and pegmatites. Anomaly suggests infolded or overthrust sediments.
		—.021	
		—.015	
152	Asheville, N. C.	—.005	Mainly biotite granite and schist and biotite gneiss.
		+.009	
		+.003	
16	McCormick, S. C.	+.015	"Granites."
		+.017	
		+.023	
151	Charlotte, N. C.	+.015	Biotite granite, 2.7 specific gravity. Diabase dikes in vicinity.
		+.029	
		+.033	

TABLE C—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
154	Winston-Salem, N. C....	—.038 —.034 —.030	Granites (orthoclase, plagioclase, quartz, and biotite), with gneisses and diabase dikes. Near northwest edge of pre-Cambrian and possibly thrust on Paleozoic and pre-Cambrian sandstone and shale.
102	Cloudland, N. C.....	+.004 +.021 +.012	Roan gneiss (overthrust); hornblende gneiss and hornblende schist, with some diorite. Station on mountain top.
103	Hughes, Tenn.....	—.029 —.012 —.021	Cranberry granite; feldspar, quartz, mica, relatively light. Foot of Mountain of Roan (hornblende) gneiss, 1,000 feet higher, overthrust probably on sedimentary strata.
91	Durham, N. C.....	+.036 +.038 +.044	Diabase dikes in Triassic on crystallines, including hornblende epidote schist; 2.94 specific gravity.
19	Charlottesville, Va.....	—.013 —.011 —.005	Vertical Cambrian sandstone, shale, and arkose, altered to quartz-mica schist, quartzites, and graphitic shale and cut by amphibole dikes.
214	Fairfax, Va.....	+.036 +.037 +.044	Narrow vertical belt of phyllite in biotite granite.
212	Rockville, Md.....	+.046 +.048 +.054	Wissahickon gneiss, near contact with granite gneiss.

The minus anomaly (.018) at Plainsboro, three miles southeast of Princeton and probably on or near the border of the overhanging Piedmont, may reflect less weight of the rocks of this Piedmont area than farther south, though, if the thrust-plane is very oblique the sign of the anomaly is probably due to the undershelving light Triassic.

Interior and western Piedmont.—The interior and west borders of the Piedmont region present greater complexities, both in structure and composition, and, unfortunately, have been covered with less detailed mapping. Consequently, information as to local conditions, including rock densities, is exceptionally unsatisfactory. However, as shown in Table C, most of these stations show plus anomalies, which at half the stations are moderately large or very large. The occurrence of a large minus anomaly, .029, at Hughes, on the western border of the Piedmont, and the small size of the plus anomaly, .004, at Cloudland may in part be explained by the relative lightness of the Cranberry granite, which

here appears to be comparatively free from heavy minerals, while the Cloudland station, about three miles distant, stands 1,000 feet higher on the summit of the topography, which is composed of the hornblendic Roan gneiss. The possible effects of topographic relations and contrasting density of rocks beneath these two stations are, however, most effectively supplemented or even dominated by the influence of an enormous thickness of Cambrian and pre-Cambrian sandstones and shales, more or less altered and infolded or underfaulted beneath the western border of the Piedmont. In fact, as indicated by Keith's detailed mapping,[38] the collective crystalline mass on which these two stations are located is a part of a flat horizontal sheet thrust across folded synclines of Paleozoic and Proterozoic rocks—a relation that itself is competent to explain both the sizes and the signs of these two anomalies.

No information in the writer's hands respecting the structure and local rock densities at Opelika, Alabama, —.026; Atlanta, —.023, and Asheville, —.005, seems to offer plausible reasons for the minus signs of these anomalies, which are largest in the two westernmost stations. The occurrence of infolded Paleozoic sediments near Atlanta and within a few miles of Opelika, and a reported light density (2.64) in Stone Mountain, may suggestively be mentioned. Diabase underlies Durham, North Carolina, in the edge of the Triassic, which here lies in the heart of the Piedmont. Asheville, —.005, and Winston-Salem, —.038, invite special consideration in the field.

NEW ENGLAND REGION

Information as to the stratigraphy and structure at several of the stations in New England is exceptionally incomplete.[39] By coincidence, the stations are, for the most part, located on phyllites or shales and sandstones, the degree of alteration of which may account in part only for the generally small size of the anomalies (see Table D). The plus sign at the stations at Boston, .005, and Cambridge, .005, may be due to the diabase intrusives in the vicinity. Surely, however, no great masses of unusually heavy rock are indicated by any of these anomalies. The anomaly is roughly equivalent to the effect of 200 feet of rock of density 2.67. It will be recalled that a violent earthquake occurred in this vicinity in 1775.[40]

[38] U. S. Geol. Survey Geol. Atlas, Folio No. 151; see also Folio No. 90 and maps of adjacent quadrangles.

[39] For most of the data in the table the writer is indebted to his colleagues, Arthur Keith and Laurence La Forge. General geologic relations are shown on State geologic maps, U. S. Geol. Survey Bull. 597, and Geol. Atlas, Folio No. 158.

[40] Irving B. Crosby: The earthquake risk in Boston. Jour. Boston Soc. Civil Engr., vol. x, 1923, p. 421.

The anomalies at Worcester, Massachusetts, —.020, and Lancaster, New Hampshire, —.018, accord with the great thickness of arenaceous or graphitic phyllite and quartzite at the former locality, which is in an area of negative deflection, and with the upturned fossiliferous Devonian and Silurian shales and slates at the latter. North Hero, Vermont, with a plus anomaly, .001, falling within the range of error, strictly belongs in the Appalachian Trough. Its location in Ordovician shales might be expected to give a reasonably large minus anomaly, if the basin were broad and the full thickness of Paleozoic sediments were present above Piedmont rocks of merely average density.

New England offers the opportunity for some very instructive gravity observations, which it is hoped may be made, with accompanying records of deflection.

TABLE D

New England

(Crystalline, Metamorphic, Triassic, and Less Altered Paleozoic)

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
28	Worcester, Mass.	—.020 —.015 —.012	Vertical upper Paleozoic phyllites, locally fossiliferous.
29	Boston, Mass.	+.005 +.008 +.013	Rocks not exposed at station. Cambridge slate, probably cut by diabase.
30	Cambridge, Mass.	+.005 +.009 +.013	Cambridge slate; in vicinity cut by diabase dikes.
268	Hartford, Conn.	+.009	In Triassic; diabase sill a few miles west dipping eastward.
128	Rockland, Me.	—.015 —.013 —.007	Cambrian (?) phyllites, metamorphosed sandstone, and slate, flanked by Cambrian limestone syncline.
31	Calais, Me.	—.008 —.007 .000	Slightly altered shales, etcetera, near "Granite."
106	Fort Kent, Me.	—.013 —.014 —.005	Steep syncline, fossiliferous Devonian and Silurian shales and slates.
129	Lancaster, N. H.	—.018 —.011 —.010	Syncline, fossiliferous Devonian and Silurian shales and slates.

ADIRONDACK AREA

The discussion of the anomalies in and about the Adirondacks (see Table E) requires more detailed knowledge of the stratigraphy and

lithology than the writer commands.[41] The rather large plus anomaly, .021, at Potsdam (Station 87) conforms to the thinness of Potsdam sandstone, which may, however, rest on granite, Grenville limestone, or even gabbro. The deflection observations indicate heavy matter in this region. The small plus anomaly, .006, at Lake Placid (Station 86), on the other hand, is possibly due to lighter rocks beneath this part of the central Adirondacks.[42] Structural and topographic factors are, however, also to be considered, since the station probably lies on Grenville gneiss and quartzite (possibly on anorthosite or syenite) considerably lighter, perhaps, than the igneous rocks of the surrounding mountains. In contrast with Lake Placid, and particularly Potsdam, the absence of heavy rocks within moderate distance under Watertown (Station 132), whose anomaly is —.025, suggests as probable the presence of relatively light pre-Cambrian rocks beneath the Beekmantown limestone and the Potsdam sandstone. The deflection at Watertown is toward the northeast.

TABLE E

Adirondack Region

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
86	Lake Placid, N. Y.....	+.**006**	Pleistocene, and Grenville gneiss—specific gravity, 2.85—and quartzite, on anorthosite or possibly quartz syenite 2.68, specific gravity.
		+.016	
		+.014	
87	Pottsdam, N. Y.....	+.**021**	Thin Potsdam (Cambrian) sandstone, probably on Grenville or gabbro.
		+.021	
		+.029	

The anomaly, —.024, at Little Falls (131), which is located on a pre-Cambrian boss or dome of "augite-syenite" ringed by Beekmantown, is in large part, at least, explained, if the published analysis of the intrusive, which shows very little iron or heavy minerals, is representative. The estimated density is 2.62. This station is in an area of negative deflection. It belongs perhaps more logically in the following group.

APPALACHIAN TROUGH

Valley fold region.—Deep folds of Paleozoic rocks underlain by great thicknesses of Proterozoic sediments steeply flank or are overridden, especially toward the south, by the Piedmont complex. The columnar sections of sediments are, accordingly, enormously thick—over 8,000 feet

[41] See New York State Mus. Bulls. Nos. 211 (1919), 217 (1920), 185 (1916), and 77 (1905).

[42] Additional stations, carefully located with reference to the geology, are much needed in this region.

in the troughs—though the real thickness is somewhat indeterminable; the synclines are sliced and overridden. The alteration of the very old sediments, which is regionally progressive toward the east, reaches its highest degree on the eastern border of the Appalachian folds, though it is less than in the infolded pre-Triassic basins of the Piedmont area.

TABLE F

Appalachian Trough

(Valley Belt)

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
130	Whitehall, N. Y.	—.039 —.037 —.031	Cambrian shales and sandstones; Paleozoic syncline against "gneiss" of higher topography.
123	Albany, N. Y.	—.043 —.041 —.035	Folded "Hudson River shale," in great thickness, on older formations.
124	Port Jervis, N. Y.	—.033 —.027 —.025	Tilted Hamilton, Oriskany, etcetera, very thick, on older formations, in old embayment.
132	Watertown, N. Y.	—.025 —.024 —.017	Trenton on Beekmantown limestone and dolomite; Cambrian sandstone on "gneiss"; light pre-Cambrian (?) in syncline.
210	Harrisburg, Pa.	—.029 —.027 —.021	8,000± folded and nearly vertical limestone, shale, and dolomite, on 3,000± quartzite and schist.
105	State College, Pa.	—.021 —.017 —.013	Steeply tilted Beekmantown limestone and sandy oolite, on Cambrian sandstones, limestones, and dolomites.
219	Hagerstown, Md.	—.049 —.046 —.041	8,000± steeply tilted limestones, dolomites, sandstones, and shale, on 4,500 feet of shale, quartzite, and phyllites.
175	Lexington, Va.	—.024 —.019 —.016	8,000± limestone and dolomite, folded on 4,500± shales, quartzites, and phyllites.
172	Clifton Forge, Va.	—.034 —.027 —.026	500± Silurian limestones, etcetera, and 2,000 shale, thin limestone, and sandstone, on "Valley limestone," etcetera; anticlinal.
156	Bristol, Va.	—.015 —.007 —.007	Lower Knox dolomite on 2,000 shales and limestones, in syncline thrust on oblique slices of Cambrian and pre-Cambrian.
155	Knoxville, Tenn.	—.021 —.019 —.013	Knox, thrust on syncline and flat slices, including 3,000 Sevier shale, and older formations.

TABLE F—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
153	Cleveland, Tenn.....	—.023 —.020 —.015	Conasauga shale, thrust on sliced Cambrian shales, sandstones, and conglomerate; all probably on "Ocoee" (Lower Cambrian).
174	Birmingham, Ala.....	—.033 —.030 —.025	4,000± Cambrian dolomite thrust on "Coal Measures" and older formations (9,000±).

On examination of Table F it will be observed that, without exception, all the anomalies in these deep valley synclines have minus signs and that in most cases the anomaly is large. The variations in the amount of the anomaly depend in part on the occurrence of limestones of considerable thickness immediately under the station, on the attitude of the beds, and more particularly on the great thicknesses of underlying sandstones, shales, and quartzites of Cambrian and pre-Cambrian age, extending many thousands of feet below sealevel. That many of these anomalies would be much greater but for the stage of alteration of the rocks can not be doubted. In some cases heavier rock material forms the neighboring topography on the east.[43]

The alinement of this series of large minus anomalies along the western border of the Piedmont is a striking feature in a region whose peneplains have been little deformed since Cretaceous time. Not only are the plus anomalies of the Piedmont liquidated in this belt, but embarrassingly large anomalies of the minus sign are developed instead. At some of the stations, as at Birmingham (—.033), Cleveland (—.023), and Lexington (—.024) or Hagerstown (—.049), very thick sedimentary sections, containing in the aggregate great amounts of light material, are present, but it may be questioned whether the minus anomaly at any station in the list can be fully accounted for and compensated by deficiency of density in sediments beneath it.

One must, therefore, conclude that the pre-Cambrian basement beneath the Appalachian trough is lighter than the Piedmont—that is, the abnormally heavy Piedmont matter, if present, lies at very much greater depth. It is probable that the "Azoic" in this region was never eroded down, as in the older parts of the Piedmont, to the eastward. On the

[43] New York State Mus. Ann. Rept., p. 429. 1894; U. S. Geol. Survey, Geol. Atlas, Bellefonte Folio, by E. S. Moore (manuscript); Geol. Survey of Maryland, Cambrian, Ordovician, and Silurian reports; U. S. Geol. Survey Geol. Atlas, Folio No. 10; Virginia Geol. Survey State map, 1916; U. S. Geol. Survey Geol. Atlas, Folios Nos. 59, 16, and 175; also oral information kindly communicated by G. W. Stose; New York State Mus. Bulls. 153 (1911), 42 (1901), 56 (1902), 145 (1910), 146 (1911), and State map of New York.

other hand, the question may well be asked whether the heavy matter was ever brought so high in the valley region as in the Piedmont. The break-off in weight between the Piedmont and the valley trough suggests not only the higher position of the dense rock matter in the Piedmont pre-Cambrian, but also an abrupt change of influence, as though the heavy Piedmont mass were overthrust on the valley trough zone. The case is strongly in contrast with the apparent continuity of the very heavy floor of the Black Hills and Big Horn pre-Cambrian matter in the basins of the Northern Great Plains.

Allegheny basin.—In reviewing the anomalies of the Allegheny region it will be borne in mind that from the Appalachian Valley or trough zone the gently folded or nearly flat terranes extend with generally decreasing thickness toward the zone of the Nashville and Cincinnati arches, at the north end of which the remaining formations aggregate less than 3,000 feet. The westward thinning of the formations, due in part to non-deposition of members, is especially noticeable in the Pennsylvanian, Mississippian, and Devonian. The older Paleozoic section also undergoes great changes, with loss of many formations beneath the great Devonian basin. Between Latrobe, Pennsylvania, and Lower Loup Creek near Charleston, West Virginia, several wells started in "Coal Measures" reached the Oriskany at depths of a mile to a mile and a half. In Vinton County, southeastern Ohio,[44] gas is produced from the Medina at moderate depth (2,500 feet) and the Trenton is found 1,200 feet deeper; but beneath the outcrop of the Devonian "black" shale, the "crystalline" lies within reach of the drill at less than 4,000 feet.

At the same time the eastern and thicker sections carry larger proportions of shale and sandstone, the effect of which is, however, partly offset by greater density, due to progressive regional horizontal stresses, with consequent progressive dehydration and lithification. Simultaneously the proportion of limestone in the sedimentary columns, especially in the Mississippian and the Silurian, increases westward, and the limestones of the "Coal Measures" become relatively more prominent. Little is known, however, as to the Silurian or older Paleozoic formations between the gas fields of the "Clinton" sand, not very far west of the Ohio River, and the outcrop of the Medina at the eastern margin of the coal field, in strike with Cumberland, Maryland, and Tyrone, Pennsylvania. It is not known whether pre-Cambrian sediments underlie any of these stations.

[44] J. A. Bownocker: Petroleum in Ohio and Indiana. Oil and Gas, vol. 9, no. 18, pp. 36-43, Chicago, 1921. L. S. Panyity: Oil and gas-bearing horizons of the Ordovician system in Ohio. Bull. Am. Assoc. Pet. Geologists, vol. 5, no. 5, September-October, 1921, pp. 609-619; also U. S. Geol. Survey Bull. 693, p. 11.

TABLE G

Appalachian Trough (Continued)

(Allegheny Basin)

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
85	North Hero, Vt.	+.001 −.002 +.009	In Ordovician shale, near pre-Cambrian.
131	Little Falls, N. Y.	−.024 −.021 −.016	Beekmantown and older dolomite, limestones, etcetera, around small uplift of "augite-syenite." (Estimated density, 2.62.)
32	Ithaca, N. Y.	−.023 −.020 −.015	Upper Devonian and thick older Devonian; 1,600 to Salina. Older Paleozoic present.
133	Southport, N. Y.	−.030 −.024 −.022	Chemung sandstone and shale and underlying Devonian shale and sandstone and other Paleozoic formations.
211	Pittsburgh, Pa.	−.023 −.022 −.015	1,800 Carboniferous sandstone, shale, clay, coals, and some thin limestone. About 4,800, mostly shale and sandstone, in Devonian. Older Paleozoic probably present.
207	Wheeling, W. Va.	−.029 −.026 −.021	Near axis "Coal Measures" syncline. Sandstone, shale, clay, thin limestone, of lower Permian, Carboniferous, and Devonian. Well 4,500, in Devonian. About 6,560, surface to Medina sandstone.
20	Deer Park, Md.	+.010 +.022 +.018	Top of Jennings (Chemung), 9,000± to base of Silurian, on anticline (see Table T).
135	Parkersburg, W. Va.	−.024 −.023 −.016	Near axis "Coal Measures" syncline; 2,000 Carboniferous sandstone, shale, clay, and thin limestone, on Devonian, etc. Probably 7,000+, surface to base of Silurian.
104	Charleston, W. Va.	−.024 −.024 −.016	Allegheny ("Coal Measures"); 5,500± to Oriskany; older rocks probably present.
176	Prestonburg, Ky.	−.024 −.022 −.016	Upper Pottsville (1,500) and older. Well 2,610 at Maytown, in Mississippian at 950; ends 80 in Corniferous.
101	Helenwood, Tenn.	+.040 +.045 +.048	West slope "Coal Measures" basin; 800 Pennsylvanian on Mississippian, etcetera. Well eight miles south, in Chickamauga, at 1,800.

TABLE G—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
166	Huntsville, Ala.	—.023 —.021 —.015	Warsaw, etcetera, sandstone, shale, limestone; well 2,647; base of Trenton horizon at 1,400±. Probably 3,500, surface to base of Knox, +1,000± shale and limestone. (Pre-Cambrian present ?.)
94	Aliceville, Ala.	—.017 —.017 —.009	800± Cretaceous sandstone, conglomerate, shale, and clay, and 3,000 "Coal Measures," sandstone, etcetera, on Mississippian and older rocks.
171	Danville, Ky.	—.030 —.026 —.021	2,300±, mostly limestone and dolomite, upper Trenton horizon to Cambrian. On Kentucky River fault. Well at Nicholasville in Cambrian (?) at 3,185.
88	Wilson, N. Y.	—.010 —.013 —.002	Medina sandstone and shale, and underlying Paleozoic.
134	Erie, Pa.	—.027 —.027 —.019	Upper Devonian shale, with great thickness mid-Devonian, followed by older beds.
33	Cleveland, O.	—.003 —.003 +.005	Basal Mississippian shale and sandstone, on Devonian shale, sandstone, and limestone. Well in top of Trenton (?) at 4,482.
136	Columbus, O.	—.012 —.011 —.004	Columbus limestone, Devonian shale, and older rocks. 3,500± to pre-Cambrian crystallines.

An inspection of the list of the anomalies for this region (Table G) shows that, among the 18 stations, only two, Deer Park, +.010, and Helenwood, +.040, have the plus sign. With these two somewhat glaring exceptions, to which particular reference will later be made (see page 271), it appears that not only are the anomalies negative over the thick and relatively light sedimentary sections of the Allegheny basin, but they are greatest over the maximum arenaceous sections on the eastern side of the basin and in the regions of the axes of the Pennsylvanian synclines, where light shale, sandstones, and coals with thin clays and thin limestones of the "Coal Measures," Mississippian, and Devonian form the greater part of the sections.[45]

At most of the stations in the Allegheny basin the amount of the

[45] See U. S. Geol. Survey Geol. Atlas, Folios Nos. 169, 134, 177, and Bull. 693; West Virginia Geological Survey County Reports, Ohio, Brooke, and Hancock counties, Pleasants, Wood, and Ritchie counties, Kanawha County; Maryland Geological Survey County Reports, Allegheny County and Garrett County; U. S. Geol. Survey, Geol. Atlas, Folios

anomaly, which has the minus sign, is much greater than the apparently allowable compensation for deficiency in weight of the sedimentary column. The situation is therefore comparable to the valley trough, and it is evident that in these regions also any considerable amount of heavy matter that may be present lies very much deeper beneath the surface of the pre-Cambrian floor than in the regions of eroded pre-Cambrian, like the Piedmont; also, it is evident that the density of the floor varies, as is to be expected. However, gravity observations distributed over other portions of the Appalachian geosyncline will probably bring to light other points than Deer Park at which plus anomalies, resulting from the influence of underlying heavy rocks, will be found.

NASHVILLE-CINCINNATI AREA AND EASTERN INTERIOR PALEOZOIC SYNCLINE

Nashville-Cincinnati axes.—The region embracing the Nashville and Cincinnati axes is well known as a generally positive area of comparative stability through the greater part of the Paleozoic as well as in later periods. It may, accordingly, be presumed to be in long-standing approximate equilibrium. Further, the reduced thickness of many of the formations on or near the axes and the general predominance of limestone and dolomite, especially toward the south, appear to justify the expectation of small anomalies, the sign depending more largely on the presence or absence of concealed thick pre-Cambrian sediments, on the local composition of the underlying complex, with possible upward injection of heavy igneous matter, or on the possibly deep erosion of a pre-Cambrian arch, than on the character of the known Paleozoic strata.[46]

The small anomalies at Hopkinsville and Indianapolis (Table H), the former on limestone faulted against Pennsylvanian, the latter on Devonian shale, approach expectations. Contradictorily, the rather large size and the opposite signs at the axial localities, Columbia, Tennessee (+.026), and Cincinnati (—.019), are incompatible with the supposed thicknesses, if not with the composition of the sediments, and probably find their causes not only in buried topography, or structure dating from ancient lines of weakness, folding, and erosion, but also in variations in the density of the Cambrian floor. Columbia lies on or near the east-west trend of peridotitic magma. Evidently, the pre-Cambrian material

Nos. 28, 160, 72; Kentucky Geol. Survey Bull. 1, and ser. 6, Bull. 1; U. S. Geol. Survey Geol. Atlas, Folios Nos. 33 and 53; Alabama Geol. Survey Bull. No. 22; Second Geological Survey of Pennsylvania, Report Q-4; U. S. Geol. Survey Geol. Atlas, Folio 197, and Cleveland Folio, by F. B. Van Horn and H. P. Cushing (manuscript).

[46] For partial data see Handbook of Indiana Geology, Geological Survey of Indiana, 1922; Geol. Survey of Kentucky, Bull. 1, ser. v, 1919, and Bull. 1, 1905, Cincinnati Folio (E. O. Ulrich manuscript), and U. S. Geol. Survey Geol. Atlas, Folio 95.

under Cincinnati is light. In this connection attention may be drawn to Danville, Kentucky (Station 171), high on the flank of the arch. The anomaly (—.030) is comparable to that at Huntsville, Alabama (—.023), where structural relations to Columbia, Tennessee, are in some respects similar to those of Danville to Cincinnati. The Columbia anomaly (+.026) is equivalent to an excess of slightly more than 1,000 feet of strata of average weight (2.67). If the Nashville dome is overloaded, it must have been still heavier when the elevation of the region in late Eocene expelled the sea from the upper part of the Mississippi embayment. In this connection it may be remarked that all the stations about the north end of the embayment give minus Hayford anomalies.

TABLE H

Nashville-Cincinnati Axis

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
14	Columbia, Tenn.	+.026	500 limestone to base of Stones River. Well near Lawrenceburg, in Paleozoic, at 2,000.
		+.028	
		+.034	
170	Hopkinsville, Ky.	+.006	Fredonia (Mississippian), to pre-Cambrian, 4,250±, mostly limestone and dolomite, with some shale and sandstone. Fault near station, with "Coal Measures" on south side; top of Devonian at 1,520.
		+.007	
		+.014	
34	Cincinnati, O.	—.019	Top of Cincinnati to base St. Peters, 1,250, shale, limestone, dolomite limestone. On very stable and relatively positive arch.
		—.019	
		—.011	
137	Indianapolis, Ind.	+.001	In Devonian. Well 3,600 Silurian to "Granite" at Greentown.
		+.002	
		+.009	
122	Angola, Ind.	+.011	In Mississippian; 1,500, top of Devonian to top of Trenton (?) +1,600± to pre-Cambrian. Well at Findlay, Ohio, in hornblende granite with heavy minerals at 2,770.
		+.012	
		+.019	

TABLE I

Eastern Interior Syncline, Illinois-Indiana

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
36	Chicago, Ill.	—.007	Niagara dolomite, 300, plus 900 sandstone and shale to Cambrian sandstone (600+). Well in "red sand" at 2,243. West Chicago well 300 in Cambrian sandstone at 2,081.
		—.009	
		+.001	

TABLE I—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
37	Madison, Wis.	—.**005** —.005 +.003	1,000 Cambrian sandstone, conglomerate, and shale on Archean (?). Well 740 feet to diabase.
120	Keithsburg, Ill.	—.**008** —.008 .000	Mississippian. Well at Burlington, 1,630 shale, limestone, sandstone, and dolomite, to Cambrian; in Cambrian at 2,430. Tipton, Iowa, well 2,220 to base Cambrian, +425 Algonkian (?). Aledo, Illinois, well in Cambrian at 3,115. Pre-Cambrian sandstone possible.
35	Terre Haute, Ind.	—.**009** —.010 —.001	"Coal Measures" shale, sandstone, clay, thin limestone, and coals. Well in Clark County, Illinois, 3,017 in top of Trenton (?). Devonian at 1,550.
138	Springfield, Ill.	—.**016** —.017 —.008	"Coal Measures" shale and sandstone, 500; +225 limestone; +500 mostly shale, to Devonian limestone, +1,000 to St. Peters. 4,000± to granite.
38	St. Louis, Mo.	—.**005** —.007 +.003	1,450, mostly limestone, to St. Peters sandstone, +2,000, mainly limestone, to "Granite."

Eastern Interior basin.—The anomalies of the Illinois-Indiana coal field basin (see Table I) all are comparatively small and have the minus sign, which is worthy of note, since all of the stations are supposed to stand on less than 4,500 feet of strata[47] and some of them are probably less than 3,500 feet above the "granite." As with other basins, the largest anomaly, —.016, at Springfield, is toward the center of the syncline, where the light Pennsylvanian approaches its maximum thickness. Most of the anomalies accord with the observations at stations on sediments of nearly equal thickness in Ohio and Indiana. Roughly calculated, the deficiency in weight of the sediments nearly compensates the anomalies and the region as a whole is nearly "in balance." None of the results indicate unusually heavy rocks beneath the floor of those parts of the basin in which the stations are located. Pre-Cambrian sandstones or shales may occur locally and are known to be present toward the northwest.

It is reasonably certain not only that the rocks in the Cincinnati arch are lighter than in the Nashville dome, but also that both in the Cin-

[47] See U. S. Geol. Survey Folio 81; Geologic map and reports of Geol. Survey of Wisconsin; U. S. Geol. Survey Water Supply Paper 293; Illinois Geol. Survey Bull. 24, 1914, and U. S. Geol. Survey Folio 188 and Bull. 438.

cinnati arch and in the Eastern Interior basin the Paleozoic or pre-Cambrian floor is much lighter than the rocks at the surface in the Piedmont or beneath the low Deer Park arch. The heavy matter which dominates the latter regions, if present in the other areas, as is presumable, must lie very much deeper. The basement of the Eastern Interior area, and of western Ohio, appears comparable in weight to that of the Ozark region of southern Missouri, eastern Oklahoma, and in Arkansas, as will later be seen.

On the other hand, with the Eastern Interior, as with the Appalachian basin, one who views the anomalies without reference to the rocks underlying the stations must conclude that the synclinal region is deficient in load and uncompensated, notwithstanding its relative stability through ages. It would, however, appear that the southwest corner of the Illinois basin is possibly undergoing readjustment[48] with reference to the flanking Ozark mass, which, paradoxically, is apparently characterized by plus anomalies.

Between the Appalachian, Illinois, and Michigan synclines there is a broad, flat, bifurcating or deltoid arch in the region of southwestern Michigan, northeastern Indiana, and northwestern Ohio, in which the granite floor rises comparatively near the surface. Hornblende granite is met at a depth of but 2,770 feet at Findlay, Ohio,[49] and crystallines are met at slightly greater depths at several other points in this State and Indiana. This thinning affects Angola, Indiana, which has a plus anomaly (.011), and it possibly accounts for the small plus (.002) result at Grand Rapids, Michigan. The deflection observations indicate heavy material in the area embracing Angola.

LOWER MICHIGAN SYNCLINE

In the lower Michigan syncline there are no very deep borings, and glacial drift mantles much of the region. Hence the very rough estimates, around 4,000 to 5,000 feet for the thicknesses of the Paleozoic at the stations given in Table K, are subject to drastic revision.[50] The stations encircle the Pennsylvanian basin; none are located in the deep portion. Limestone, dolomite, shale, and sandstone occur somewhat irregularly in the columns, the carbonates, everywhere predominant, being more conspicuous to the southwest. If the sedimentary columns are as thick as estimated—they probably are somewhat thicker—the plus

[48] M. L. Fuller: New Madrid earthquake. U. S. Geol. Survey Bull. 494, 1912, pp. 70-76.

[49] D. Dale Condit: Deep wells at Findlay, Ohio. Am. Jour. Sci. (4), 36, 1923, p. 123.

[50] U. S. Geol. Survey Prof. Paper 71; Geol. Survey of Michigan reports and Michigan Geol. and Biol. Survey Pub. No. 12.

anomalies prevailing in this basin are undoubtedly due in part at least to the density of the limestones and dolomites in the sections. On the other hand, some of the heavy rock matter which strongly influences the pendulum in the region to the northwest may, from relatively deeper position, exert minor effects at some of the few Michigan stations. Windsor, Ontario, +.012, is on the axis termed Cincinnati by Keith.[51] The Alpena anomaly suggests synclinal conditions, or Paleozoic strata of moderate weight topped by Devonian may here be underlain by pre-Cambrian sediments of lighter types, such as are found at several points northward and westward.

TABLE K

Michigan Syncline

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
121	Grand Rapids, Mich....	+.002 +.002 +.010	Mississippian limestone, dolomite, shale, and sandstone; Devonian shale and limestone; Ordovician limestone and dolomite. In all probably 4,000+.
18C	Windsor, Ont.....	+.012	Limestone, dolomite, shale, and sandstone. Silurian, Ordovician (and Cambrian?).
89	Alpena, Mich.....	—.020 —.019 —.012	Devonian limestone and shale; Silurian dolomite, sandstone, and shale; Ordovician shale, dolomite, and sandstone. Total, 4,500±. Pre-Cambrian present?
177	Traverse City, Mich.....	+.001 .000 +.009	4,000± Devonian and older. Possible pre-Cambrian.

REGION OF PRE-CAMBRIAN METALLIFEROUS SEDIMENTS

The demonstrated presence in portions of Wisconsin, upper Michigan, and Minnesota of synclines and blocks of very thick pre-Cambrian formations, some of which carry heavy igneous rocks or great deposits of iron ore, and some of which are below the average in density, offers exceptional opportunities to observe the possible effects on the pendulum of unusually heavy masses and sheets of rock comparatively near the surface of the ground. The stations are relatively numerous, though in general not well located geologically, and the anomalies, which present some striking contrasts, as is to be expected, merit the close study of a geologist familiar with the ranges and districts.[52] In this study regard must

[51] Oral communication.

[52] A. C. Lane: Weight of sedimentary rocks per unit volume. Bull. Geol. Soc. America, vol. 33, 1923, p. 369.

be paid to the extent, shape, and attitude of the heavy rock-masses, as well as to their depth, thickness, and relations or structure. It is unfortunate that these relations are in some areas concealed by the thick mantle of drift. The comments given in Table L are fragmentary, may omit most important facts or indicated relations, and may in cases even be erroneous.[53]

TABLE L

Region of Pre-Cambrian Metalliferous Sediments

(Lake Michigan to the Dakotas)

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
12C	Saulte Ste. Marie, Ont.	—.**021**	Lake Superior sandstone and probably thick pre-Cambrian of light composition.
178	Seney, Mich.	+.**001** +.002 +.009	Thin Ordovician limestone and dolomite; thin Lake Superior sandstone; pre-Cambrian probable.
218	Tamarack Mine, Mich.	+.**031** +.031 +.023	Four-mile wide belt basic lavas between upper Keweenawan sandstone and Cambrian. Keweenawan copper district.
203	Duluth, Minn.	+.**050** +.049 +.058	Duluth gabbro laccolith in upper Huronian.
57	Iron River, Mich.	+.**038** +.041 +.046	Iron ore belt in upper Huronian.
107	Prentice, Wis.	+.**024** +.026 +.032	Lower Huronian acidic intrusion, near contact Keewatin green schist.
58	Ely, Minn.	+.**023** +.023 +.031	Contact Soudan formation and Ely greenstone basic igneous (Keewatin). Vermillion Iron Range.
74	Minneapolis, Minn.	+.**059** +.057 +.067	330 Ordovician and Silurian sandstone and limestone; 650 Cambrian sandstone and shale; 1,125 "red clastics" in syncline on granite (quartz, feldspar, hornblende, and chloritic minerals).
196	Faribault, Minn.	+.**036** +.035 +.044	1,000 drift, sandstone and shale (265 dolomite near top) to "red clastic" series. Probably igneous beneath 100± "red clastic."

[53] U. S. Geol. Survey Prof. Papers 71 and 106; Water Supply Papers 145 and 256; F. T. Thwaites, The Paleozoic rocks found in deep wells in Wisconsin and northern Illinois: Jour. of Geology, vol. 31, no. 7, 1923, p. 529; U. S. Geological Survey 10th Ann. Rept.; 15th Ann. Rept., pt. E; 19th Ann. Rept., pt. iii-a, and 21st Ann. Rept., pt. iii-c; Monographs 19, 36, 43, 45, and 52 and Geologic Folio 201.

TABLE I.—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
182	Baldwin, Wis.	—.050 —.051 —.042	Thin "Lower Magnesian" on Cambrian (1,000) sandstone, shale, conglomerate, and limestone. Possibly on syncline of undifferentiated Huronian (5,000±).
183	Cumberland, Wis.	—.049 —.048 —.041	In Cambrian, probably on undifferentiated Huronian (5,000±) conglomerate, quartzite, shale, tuffs, and dolomite, more or less altered.
184	Cambridge, Minn.	—.027 —.028 —.019	Thick drift, probably on older Paleozoic.
180	Grand Rapids, Wis.	—.042 —.042 —.034	Biwabik formation. Mesabi iron district.
179	Oconto, Wis.	—.025 —.027 —.017	200 Ordovician on St. Peters sandstone and 1,000± Cambrian sandstone, shale, conglomerate, and limestone. Probably pre-Cambrian also.
204	Osage, Ia.	—.026 —.025 —.018	780 limestone, dolomite, shale, and sandstone, Devonian to base St. Peters; probably 300 Ordovician dolomite and 800 Cambrian; on pre-Cambrian sandstone (?).
181	Winona, Minn.	+.015 +.015 +.023	510 sandstone and shale to granite.
197	St. James, Minn.	+.006 +.005 +.014	150 drift +450 Cretaceous and Cambrian sandstone to "red clastic series."
200	Cokato, Minn.	+.006 +.005 +.019	Thick drift.
199	Dawson, Minn.	+.017 +.015 +.025	150 Pleistocene and Cretaceous to granite.
185	Brainerd, Minn.	+.012 +.012 +.020	Upper Huronian slates (magnetic).
191	Crookston, Minn.	+.011 +.008 +.019	Lake deposits on Cretaceous. Underlying rocks not known.
108	Fergus Falls, Minn.	—.006 —.008 +.002	Thick drift. Data as to underlying rocks not in hand.

The large plus anomalies at Iron River (.038) and Ely (.023) undoubtedly reflect some influence of the heavy metalliferous rocks of the areas, and there can be no question as to an important rôle played by the heavy gabbro laccolith in causing the very large anomaly, +.050, at Duluth, or that the plus anomaly, .031, at Tamarack is in part, possibly mostly, due to the heavy materials in that locality. The large excess in weight (+.059) recorded beneath Minneapolis may arise from heavy igneous under the "red clastic," if not from the latter, the density of which is unknown to me. The rather large minus anomaly at Oconto, Wisconsin, over what is supposed to be a relatively thin Paleozoic remnant suggests the presence of a basin of pre-Cambrian sandstones and shales in this area. I offer no suggestion in explanation of the large minus anomaly (.042) recorded at the Grand Rapids, Wisconsin, station. Further geological data should solve the problem, which may be structural.

On the other hand, some large anomalies with the minus sign in the midst of the points of excessive weight appear to be located in areas of thick quartzites, sandstones, etcetera, in buried pre-Cambrian synclines and fault-blocks. Baldwin (—.050), Cumberland (—.049), and Cambridge (—.027) possibly fall in this category. With seeming great deficiencies, they lie in the midst of stations of indicated great density—Baldwin, with —.050, being less than 50 miles from Minneapolis, which gives a still larger anomaly, .059, with the opposite sign.

More complete information as to the density, thickness, and structure of the rocks beneath these stations will, I believe, undoubtedly permit important reductions, at least in the departures from the normal, thus reducing the element of mutual compensation between stations, if, indeed, the anomalies may not be approximately discounted and compensated by the geological conditions existing relatively close to the surface. This assumption predicates a degree of localization of the excessively heavy matter, that itself points to a high position, with restricted horizontal radius of influence. Localization of abnormal weights finds additional support in the remarkable deflection records of this region.

Studies of the underground water geology of the southern region of Wisconsin and Minnesota and of northern Iowa show an uneven granite topography on which rest basins or remnants of pre-Cambrian sediments, generally quartzites and shales. These, as well as the Cretaceous overlap, are to be reckoned with and complicate the calculated thicknesses of sediments, both in the regions under consideration and in areas to the south and west. At most points in southern Wisconsin and the southern border zone of Minnesota the sedimentary material, including pre-Cambrian

sands and shales, is thin and the anomalies appear in sign as well as amount compatible with the character of the known or roughly estimated thicknesses of the strata and the probable variability in the granitic basement. The anomalies justify the inference that the pre-Cambrian crystalline basement in this southern area and in western Minnesota is in density of its upper zones broadly comparable to that beneath the Eastern Interior basin, the Cincinnati arch, and the Ozark uplift.

The entire area between Lake Michigan and Red River is one of extraordinarily little deformation since Cambrian time. Forming a part of the great region of the continent uplifted at the end of Cretaceous time and subjected for long periods to erosion, the anomalies are mainly plus. Is not the latter circumstance due more probably to the rocks within five miles of the pendulum than to lack of equilibrium?

NEMAHA MOUNTAIN ZONE

The progressive search for oil and gas in the mid-continent region has revealed the presence and is developing the positions and forms of a group or series of granite knobs or ranges which stretch from the southeast corner of Nebraska, where granite is struck at about 500 feet, across eastern Kansas and into northern Oklahoma. These buried lands are probably continuous with the pre-Cambrian crystalline region of southwestern Minnesota. The ancient topography is more deeply concealed under "Permo-Carboniferous" beds toward the south, being at a depth of about 2,100 feet near Ponca City, Oklahoma, and is less known to the southwest, where, however, the granite is believed to join the westward extension of the Wichita Mountain axis, from which granite here and there protrudes through the horizontal "Red Beds" far to the west of the mountain mass. In the Panhandle of Texas granite is met at about 3,000 feet. These granite knobs have been described and mapped by Powers,[54] by Moore,[55] who named them the Nemaha Mountains, by Gould,[56] and by others.

The western border of the Nemaha Mountains is not yet definitely marked, though several wells of moderate depth west of the known granite have ended in normal Pennsylvanian or older strata. Beyond the Nemahas lies the great Mesozoic basin of the western Great Plains, later to

[54] Sidney Powers: Granites in Kansas. Am. Jour. Sci., vol. 44, 1917; also, Reflected buried hills and their importance in petroleum geology. Economic Geology, vol. 17, 1922, pp. 233-259.

[55] R. C. Moore: Crystalline rocks of Kansas. Kansas Geol. Survey Bull. 3, 1917, p. 140, and The relation of the buried granite in Kansas to oil production. Bull. A. P. G., vol. 4, 1920, p. 254.

[56] C. N. Gould: Crystalline rocks of the plains. Bull. Geol. Soc. America, vol. 34, 1923, p. 541. (Gives bibliography.)

be discussed. On the east of these ranges basins of pre-Cambrian sandstone, probably the Sioux quartzite, have been struck at several points in Iowa, western Missouri, and northeastern Oklahoma.[57] The "Granite Knob" area is one of relative quiescence, the doming of the overlapping Pennsylvanian or Permian over the summits being, perhaps, due as much to shrinkage by dehydration, devolatilization, and compression of the sediments as to post-Permian deformation. It is probable that the pre-Cambrian varies in density in this region as well as in other regions.

None of the published gravity observations shown in Table M pertain to points known to lie directly over the Nemaha Mountain zone, and it is possible that the moderate plus anomaly (.014) at Ellsworth, Kansas, which, if the sediments are thick as estimated, indicates somewhat heavy rocks at no very great depth, falls quite beyond its influence, provided, of course, the column at this point is in equilibrium. The matter under Ellsworth is evidently heavier than that in the knobs at Seneca or Zeandale, as will be seen. The anomaly suggests some complexity in the composition and early history of the region.

TABLE M

Nemaha Mountain Region

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
119	Fort Dodge, Ia.	+.015 +.013 +.023	Permian (?); well 59 feet in Cambrian at 1,768; mostly limestone. Pre-Cambrian possible, but probably on pre-Cambrian topography.
40	Ellsworth, Kans.	+.014 +.012 +.022	250 Dakota on Permian red beds; no deep wells; well, nine miles southwest, in limestone and shale at 3,045. Well thirteen miles east, shale, limestone, clay, and sandstone, 4,007, probably in Ordovician.
72	Shamrock, Tex.	+.032 +.034 +.040	Permian red beds. Well four miles north, 2,040, in "Permo-Carboniferous." "Granite" at 3,375 in well sixty-five miles west.

The large plus anomaly (.032) at Shamrock, Texas, where the sediments, composed of light shales, sands, clays, salt, gypsum, and limestone, probably do not exceed 3,500 feet in thickness, points to the presumable presence there of unusually heavy igneous or metamorphic rock, such as is found in the Arbuckle-Ouachita zone of folding, in or near which the

[57] U. S. Geol. Survey Water Supply Paper 293, 1912; Missouri Bur. Geol. and Mines (2), xvi, 1922.

station lies. Granite is met at 3,375 feet in a well 65 miles west of Shamrock.

The profile of the granite shows 2,000 feet of relief in early Pennsylvanian time. In order to learn whether the long quiescent Nemaha Mountains present heavy igneous matter within this relief, and with the object of experimentally determining whether these granite knobs can be detected by means of the pendulum in areas not explored by the drill, the Coast and Geodetic Survey kindly established three stations on or near two of these knobs in northern Kansas.

Station 299 was located at the Seneca well, near Seneca, Kansas, where red granite was reached at a depth of 586 feet. Station 297, near the Bard well, not far from Zeandale, lies 958 feet above pink, fine-grained granite, composed mainly of pink orthoclase and plagioclase, with some biotite, muscovite, and zircon, secondary chlorite, hematite, and kaolin being present. At the Wilkins well, near Sutphen, Dickinson County, where Station 296 was located, only basal Permian and Pennsylvanian strata were met in a well 2,895 feet deep. Nothing unusual was encountered to a depth of 2,700 feet at the fourth station, number 298, which was near the Doyle well, near Saint Marys, Pottawatomie County.[58] The horizontal "Permo-Carboniferous" strata are very slightly arched over the crests of the knobs, the contact being depositional and arkosic. Some variety in the pre-Cambrian matter is indicated in some of the knobs, which, however, deserve more thorough petrologic study.

It was expected that the granite knobs would give plus anomalies, the "Coal Measures" sections minus anomalies. On the contrary, the Seneca knob gives the anomaly —.032 and the Zeandale knob —.038. The anomaly at the Wilkins well is —.024, and that at the Doyle well —.022. In other words, the rocks beneath the granite knob stations are shown to be considerably lighter than those beneath the stations on the Paleozoic sediments, which, after all, is not remarkable, in view of the relatively low densities of many of the granitic types,[59] on the one hand, and, on the other, the prevalence of dense clays, limestones, and dolomites in the lower portions of the sedimentary sections of this part of Kansas, as shown in the deep drilling in the Eldorado region. All four anomalies are synclinal in aspect; and it is evident that the deficiency in weight is regional, for it can only in part be compensated by the underweight of the sedimentary columns, unless they are much longer than supposed.

[58] The locations and their relations to the known granite can readily be made by reference to Bull. Amer. Assoc. Petroleum Geol., vol. 4, no. 3, 1920, p. 257.

[59] Some average densities (usually .10 to .12 lower than specific gravities) of granitic types are as follows: Average of 10 biotite granites, 2.57; hornblende biotite granite, 2.55; average of 7 muscovite gneisses, 2.58; average of 24 granite gneisses, 2.58.

The difference, .014, between the Zeandale and the Wilkins anomalies is approximately equivalent to the compensating or deficiency effect of 6,500 feet of sediments having a variance of .18 in density. The area embracing these stations seems to lie in a light spot, in which the granite knobs are lightest. The apparent localization of the great deficiency effects in the knobs, with seeming limited lateral extent of the knob influence, points to a high position of the "lightness" in the old topography—a condition analogous to the evidence that the excessively heavy matter at some of the Wisconsin and Minnesota stations is largely local and high in the pre-Cambrian basement. Were the stratigraphic and lithologic conditions of the area more fully known, it might be possible roughly to estimate the deficiency beneath the Paleozoic, and the difference between rock weight in the knobs and in the regional basement.

The results of this experiment bear on the application of pendulum observations to the discovery of granite knobs, and so the development of new oil and gas deposits, as well as on the equilibrium of the buried knobs and the surrounding "Permo-Carboniferous" and older sediments.

OZARK UPLIFT

Beneath the stations encircling the Ozark uplift the strata are less than 3,500 feet thick (see Table N), the rocks are mostly limestone and dolomite,[60] and all the anomalies are plus and of moderate size. Saint Louis, with 3,500 feet of relatively light sediments, has a very small minus anomaly, .005. It lies within the Eastern Interior syncline.

TABLE N

Ozark Uplift

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
139	Lebanon, Mo.....	+.011 +.012 +.019	Beekmantown horizon. About 750, three-fourths dolomite, one-fourth sandstone, to "Granite." (E. O. Ulrich.)
140	Joplin, Mo.....	+.016 +.016 +.024	Boone formation. Well at Carthage, 1,750 limestone, sandstone, shale, and chert, to pre-Cambrian crystalline. Well 1,600 to base of Cambrian +1,900 "pre-Cambrian" "quartzite, sandstone, and shale," at Rich Hill.
169	Mammoth Springs, Ark.	+.013 +.013 +.021	Beekmantown horizon. Well six miles east of Pomona, Missouri, in "Granite" at 2,500 or less.

[60] U. S. Geol. Survey Bulls. 438 and 494; Folios 148 and 206; 22d Ann. Rept., part II, B; Water Supply Paper 195; reports of Missouri Bur. Mines and Geology, including vol. xvi, 2d ser., 1922, and State geologic map, 1923 edition.

TABLE N—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
95	New Madrid, Mo.	+.001 −.002 +.009	Pleistocene, Tertiary, and Cretaceous (?). Well 1,750 clay, sands, etcetera, Reelfoot Lake, Tennessee. Well in limestone at 2,000 six miles north of Proctor City.
168	Memphis, Tenn.	+.013 +.912 +.021	Well one mile north shows 100 Alluvium +880 Tertiary sands, clay, gravels, lignite; near base Ripley sands, clay, and lignite at 1,589; probably Selma at 1,793. Alignment of gas seeps north of town suggests fault or axis.

Since the Cambrian of the Ozarks is visible practically to the border of the Mississippi embayment, along the major axis of the uplift, which lies in the direction of New Madrid, it may reasonably be assumed as probable that pre-Cambrian crystallines lie less than 2,500 and possibly less than 2,000 feet below the latter point. The anomaly, virtually zero, since it falls within the limit of error of observation (.002) at New Madrid, is perhaps explained by the very light weight of the Pleistocene and Tertiary sands, gravels, and clays overlying the basal Paleozoic and granite. The movements attending the New Madrid earthquake may be construed as overthrust toward the west.[61] The results of this pendulum observation are of unusual interest, for at face value they point to approximate equilibrium at the point of greatest earthquake activity in the interior of the continent. The logs of wells in the region indicate limestones at 2,000 feet near Proctor City, Tennessee, on the east side of the fault. The north-south alinement of gas seeps north of Memphis, Tennessee, as well as the moderate plus anomaly (.013) at the latter station, may be tentatively regarded as pointing to either a fault or a buried fold bringing rocks of more than average density much nearer the surface in this vicinity than might be inferred from the stratigraphy of the exposed formations and the well logs of the region. Reelfoot Lake and Memphis may lie in a single fault-zone.

So far as the anomalies go, there is no indication of the presence in the Ozark uplift of the excessive weight indicated for the Black Hills and northern Great Plains to the northwest or of the extended Wichita-Arbuckle zone of uplift to the southwest. The rocks in the pre-Cambrian floor of the Ozark region may in general be no heavier than those in the floor of the basins to the north and east. They appear, however, to be much heavier than those in the northern part of the Nemaha Mountains in Kansas.

[61] U. S. Geol. Survey Bull. 494, 1912, pp. 70-76.

MID-CONTINENT BASIN

East of the Granite or Nemaha Mountains the late Paleozoic basin rises northward into the area of relatively flat beds in northern Iowa and deepens southward into the Ouachita synclinorium. The Carboniferous formations thicken tremendously in the latter direction, and thick limestone series of earlier age bottom the Paleozoic basin in varying depths. Further, remnantal patches or basins of pre-Cambrian quartzite and sandstone, present in the northern area, as at Rich Hill and other points in western Missouri and northeastern Oklahoma, also constitute unknown sedimentary quantities complicating the calculation of thicknesses and composition of sediments.[62]

If the moderate minus anomaly (.016) at Kansas City (Table O) is not due to deep-seated causes, it is permissible tentatively to infer that a body of pre-Cambrian siliceous sediments underlies this point, which is quite possible, for such material occurs not far to the south, though a well at Raytown is said to have ended in granite at 2,348 feet. It is interesting to note that the minus anomaly (.016) at Fort Smith is the same as at Kansas City, though Fort Smith stands on sediments probably over 7,000 feet in thickness and sufficiently under 2.67 in density to cause, as roughly calculated, a deficiency of —.018—that is, a deficiency in weight sufficient to neutralize the anomaly. Evidently, if the sedimentary section at Kansas City does not exceed 3,000 feet, about half of which is limestone, heavier material lies nearer to the top of the pre-Cambrian floor at Fort Smith than at Kansas City. The floor at Kansas City may be continuous with that of the Nemaha Mountain region, which is remarkably light. On the other hand, the rock columns at some of these localities may, of course, be out of isostatic balance. As bearing on this question it is worth while to consider several other stations on the south slope of the Ozark uplift—that is, in the long north slope of the deep Ouachita syncline.

TABLE O

"Mid-Continent" Basin

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
208	Leon, Ia.....	—.008	300 drift on Pennsylvanian shale, sandstone, and thin limestone. Well in Mississippian at 793. Probably 3,200± surface to pre-Cambrian which may be sandstone and shale.
		—.008	
		.000	

[62] U. S. Geol. Survey Bull. 606, 1915, and Geol. Atlas, Folio 206; Henry Hinds, Coal deposits of Missouri: Missouri Bur. Geol. and Mines, vol. ii, 2d ser., 1912; also (2), xvi, 1922, State geol. map, 1923, and other reports; see vol. 9 and other reports of Geol. Survey of Kansas and reports of Geol. Survey of Oklahoma.

TABLE O—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
39	Kansas City, Mo.	—.016 —.018 —.008	In Kansas City formation. Well 2,348 limestone, sandstone, and shale to "granite" at Raytown. Thick pre-Cambrian sandstone locally present. Probably light crystalline basement.
141	Fort Smith, Ark.	—.016 —.018 —.008	8,000±, nearly all shale, sandstone and some chert, to "Granite."
12	McAlester, Okla.	—.027 —.028 —.019	12,000+ shale, sandstone, chert and thin limestone to top of Ordovician. Probably 3,000± Ordovician and Cambrian limestone, dolomite, and sandstone. Station on north slope Ouachita syncline.
96	Mena, Ark.	—.052 —.051 —.044	6,000± nearly vertical Stanley shale and sandstone between 5,000± sandstone, shale, and chert, and the Arkansas novaculite. Probably over 20,000 vertically to pre-Cambrian.
143	Hot Springs, Ark.	+.018 +.018 +.026	Tilted Stanley shale and sandstone and cherts cut by ferromagnesian dikes. Heavy rock at depth. North slope Ouachita syncline. Regional thickness of sediments probably 20,000±.
13	Little Rock, Ark.	+.030 +.027 +.038	Slightly altered upper Paleozoic intruded by large masses pulaskite, elaeolite syenite, and related rocks. North slope Ouachita syncline; comparable to No. 143.

The potent influence of a great thickness of rather light sediments in producing the large anomalies at McAlester, Oklahoma, and Mena, Arkansas, is hardly to be doubted.[63] Mena, with its great —.052 anomaly, is located near the axis of the great Carboniferous synclinorium, in which, however, the siliceous sediments are in small part represented by novaculites. McAlester, —.027, with a smaller departure from the normal, is on thinner sediments, and structurally is less favorably located, being farther up the flank of the basin. In some respects conditions at Mena suggest the deepest synclines of the Appalachian Valley region, but the sediments are, as a whole, much lighter at Mena. If Mena is underlain by over 20,000 feet of sediments, mostly by far arenaceous, with very little limestone, as is very highly probable, the deficiency

[63] U. S. Geol. Survey 19th Ann. Rept., part 3-E; 21st Ann. Rept., part 2-E; Bulletins 541-B, 621 C and G, 691 C and J, 686, 716-D, 541, 540-U, 326, and 494; Geologic Folios 154 and 202 and Mineral Resources, 1913, part 2-K.

in weight of these rocks would account for about —.050 in the anomaly. What with the dip, the depth to granite may considerably exceed 20,000 feet. Similarly, the deductions to be made for weight of over 12,000 feet of sandstones and unaltered shales, with coals and clays, at McAlester approximate —.026.

It follows that the anomalies for Fort Smith, McAlester, and Mena, all at different levels on the north slope of the Ouachita syncline, are in approximate correspondence; they are approximately compensated by the thickness and composition of the underlying sedimentary sections, and they indicate nearly equal densities of the underlying basement in this part of the syncline—that is, in the south slope of the Ozark pre-Cambrian mass. They approach expectations based on the relations of the stations to the position, form, and depth of the basin and on the behavior of the pendulum under comparable conditions in other regions.

The Ozark pre-Cambrian slope beneath the Ouachita basin seems to be less dense than near the top of the Ozark uplift, on account, possibly, of the greater erosion of the latter nearer to deeper and denser material; on account, perhaps, of the rise of heavy magma beneath the central area; or, again, in part because of the greater distance between the pendulum and the granite beneath these stations. In the latter case the difference may be apparent rather than real.

In contrast to the Ozark "Azoics," the pre-Cambrian of the Wichita-Arbuckle uplift to the south of the basin is conspicuously heavy.

At Hot Springs (+.018) and Little Rock (+.030), which are rather less favorably stationed, but which stand in areas of great thickness of steeply folded siliceous rocks, the causes for the changes to the plus sign may lie in buried structure and in a possibly consequent but unexpectedly high level of the heavy magmas which cut the strata at or near both these stations. The stations lie in a peridotite zone. The intrusive phenomena which have made the region famous for its minerals are regarded as initially responsible for the temperature of the springs.

NORTHERN GREAT PLAINS—MINNESOTA TO ROCKY MOUNTAINS

From Minnesota and northwestern Iowa westward to the Rocky Mountains, the published Hayford 1912 anomalies, without exception, have the plus sign. Obviously, in this great region, which includes all of the Dakotas, northwestern Nebraska, and all of Wyoming, the influence of the sediments can only have been to reduce the amounts of the anomalies. The more important question as to the reason for the plus sign lies in the unusual density of the underlying basement. The stations

are listed with very fragmentary and incomplete stratigraphic data in Table P.[64]

In the area east of the 100th meridian, which includes Randolph, Nebraska (+.002), Mitchell, South Dakota (+.001), Aberdeen, South Dakota (+.012), and, by contiguity, Crookston, Minnesota (+.011), the stations are separated by thin covers of drift and Cretaceous, and perhaps by thin Carboniferous, or local pre-Cambrian quartzite and sandstone, from the underlying "granite." The anomalies shown at these stations, none of which exceeds .012, offer no evidence of unusual density in the upper part of the pre-Cambrian floor in this area.

TABLE P

Northern Great Plains—Minnesota to Rocky Mountains *

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
75	Lead, S. D. 1590 M	+.052 +.062 +.060	Pre-Cambrian, calcareous and magnesian schist, amphibolitic, against pre-Cambrian calcareous and garnetiferous schist. Dense rocks in elongated core flanked by Paleozoic and Mesozoic.
269	Hill City, S. D.	+.042	Pre-Cambrian schist, with pegmatite inclusions. Core of Black Hills uplift.
198	Edgemont, S. D. 1066 M	+.054 +.054 +.062	In Granerous; 3,000±, nearly all shale and sandstone, except lower part, limestone and dolomite, surface to granite and pre-Cambrian, the latter with heavy minerals.
272	Buford, Wyo.	+.046	Sherman granite; coarse-grained, chiefly pink feldspar and glassy quartz, with black hornblende and mica. Batholith, granite porphyry and granite-gneiss three miles distant.
117	Gurnsey, Wyo. 1322 M	+.036 +.035 +.044	150± Carboniferous limestone, sandstone, and conglomerate, on Algonkian schist, quartzite, limestone, and gneiss, cut by intrusives, aplite, etcetera. On flank pre-Cambrian granitic core.

[64] U. S. Geol. Survey, 17th Ann. Rept., pt. 2-G; 19th Ann. Rept., pt. 2-E; 18th Ann. Rept., pt. 4-C; Prof. Papers 26, 65, and 32; Water Supply Papers 117, 227, 428, and 34; Geol. Folios 181, 168, 165, 108, 99, 209, 127; Bulletins 541-G, 726-A, 531-E, 691-A and G, 499, 627, and 575; Possibilities of oil in South Dakota: South Dakota Geol. and Nat. History Survey, Bull. 10, ser. xxii, no. 3, 1922; Bull. Assoc. Petrol. Geol., vol. 7, 1921, p. 506; U. S. Geol. Survey Geol. Atlas, Black Hills Folio, by Sidney Paige and N. H. Darton (manuscript).

* Elevations of certain stations, in meters, are given beneath the names.

TABLE P—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
201	Wasta, S. D. 706 M	+.030 +.026 +.038	2,800±, shale, sandstone, clay, marls, and thin limestone, Pierre to Dakota; 2,500± Dakota to granite.
188	Marmarth, N. D. 822 M	+.035 +.036 +.043	On Glendive anticline; in lower Lance; 4,100± to Dakota. Older Mesozoic and some Paleozoic probably present.
193	Miles City, Mont. 718 M	+.030 +.028 +.038	Syncline. 4,600± to Dakota +3,000± top of Dakota to granite.
270	Newcastle, Wyo.	+.029	Lower part of Graneros; 1,600± shale, sandstone, and conglomerate to Carboniferous; +2,100 limestone, shale, and sandstone to "granite."
202	Moorcroft, Wyo. 1295 M	+.021 +.024 +.029	Lower Lance. 5,000± to top of Dakota; +1,300 to Minnekahta limestone, +2,200± to granite.
190	Crosby, N. D. 598 M	+.017 +.015 +.025	Fort Union. 4,200± to Dakota sandstone. Older Mesozoic and Paleozoic probably present. 5,500± to Paleozoic.
192	Poplar, Mont. 608 M	+.019 +.015 +.027	3,600± to Dakota. Older Mesozoic and Paleozoic probably present.
77	Hinsdale, Mont. 661 M	+.029 +.024 +.037	In Claggett shale; 2,970 to calcareous shale below Ellis. 2,200± to Dakota. 3,600± to Madison. On nose of broad dome.
189	Towner, N. D. 451 M	+.032 +.030 +.040	In lower Lance: Delacs well 580 in Benton at 3,980; sandy shale, clay, sandstone and thin limestone.
109	Sheridan, Wyo.	+.032 +.035 +.040	Powder River basin, fifteen miles from granite flank. 5,000± nearly all shale, sandstone, and clay to Dakota; or 9,000± surface to "granite."
187	Faith, S. D.	+.015 +.014 +.023	2,800± shale and sandstone, Lance to Dakota, +1,800± Dakota to "granite."
118	Pierre, S. D.	+.014 +.009 +.022	1,500± Pierre, Niobrara and Benton shale, sandstone, and thin limestone to "granite."
206	Valentine, Nebr. 785 M	+.018 +.020 +.026	In Arikaree shale, sandstone and clay, with thin limestone. 2,900± to Dakota sandstone. Some Paleozoic probably present. Well near Bassett, sixty miles southeast, in Lakota (?) at 2,500. Probably 5,000+ to "granite."

TABLE P—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
194	Huntley, Mont.....	+.**011** +.007 +.019	3,100 to Dakota. Shear zone on flank of anticline.
195	Lander, Wyo.....	+.**019** +.024 +.027	Mancos on flank of syncline; 3,000±, mostly shale and sandstone to Dakota, +6,800± to base of Pennsylvanian limestone. Older Paleozoic probably present.
	1635 M		
82	Rock Springs, Wyo.....	+.**013** +.020 +.021	In lower Mesaverde, on flank of dome-anticline; 8,000± (shale, sandstone, gypsum, and coals, some limestone in lower part) to Paleozoic. 4,700± Paleozoic.
205	Randolph, Nebr.....	+.**002** .000 +.010	Niobrara; 2,000±, mostly limestone to pre-Paleozoic. Pre-Cambrian sandstone probably present. Well, Sioux City, in foliated gneiss at 1,260.
60	Mitchell, S. D.....	+.**001** +.003 +.009	525 drift and Cretaceous sandstone and shale; Well 225, in Sioux quartzite, (probably 500 thick) on granite. At end of a Sioux quartzite ridge.
186	Aberdeen, S. D.	+.**012** +.009 +.020	1,267 sands, clay, shale, sandstone and conglomerate (mostly Colorado) to granite (latite, quartz, feldspar, and mica). Basement denser than at Station 60.
	396 M		
59	Pembina, N. D.....	+.**019** +.015 +.027	Older Paleozoic (on pre-Cambrian?) mostly limestone and dolomite.
76	Bismarck, N. D.....	+.**002** .000 +.010	2,100 shale, sandstone, few thin limestones, Lance to Dakota. Paleozoic present?
	516 M		
52	Lower Geyser basin....	—.**001** +.015 +.007	Thin hot springs deposits on thick section massive rhyolite flows, probably on basic breccias or Mesozoic or Paleozoic.
	Y. N. Park		
	2200 M		
50	Grand Canyon hotel...	—.**002** +.017 +.006	Glacial on 1,000+ massive rhyolite flows, probably on basic breccias (hornblende, pyroxite andesite, basalts and lavas).
	Y. N. Park		
51	Norris Geyser basin....	+.**021** +.038 +.029	2,500± Massive rhyolite flows on Paleozoic limestone and quartzite or on basic breccias.
	Y. N. Park		
	2276 M		
110	Boulder, Mont.....	—.**015** —.006 —.007	Boulder batholith. Main body probably near 2.68 specific gravity.
	1453 M		

Westward from Pierre (+.014) and Bismarck (+.002), however, we find a remarkable increase in the anomalies, concomitant with thickening of the moderately light post-Dakota sediments, and, in addition, the gradual introduction of pre-Dakota strata, including, eventually, the Black Hills Paleozoic section. Evidence that exceptionally heavy rocks occur nearer the surface, as one approaches the Black Hills from the east or south, is indubitable. The largest of the anomalies, those at Lead (+.052), Edgemont (+.054), and Hill City (+.042), occur on or close to the uncovered core along the axis of the uplift, the mass of which is geometrically suited to exercise nearly maximum influence on the pendulum. From the crest of the uplift the contours drawn on the declining anomalies, as mapped, without reference to the areal geology, in Major Bowie's report, are on all sides surprisingly parallel to the structure, including the Chadron anticline. The rapid reduction in the amounts of the great excess in the anomalies is in large part, at least, due to the thickening aggregates of strata on the flanks and in the foothills of the uplift, as may be roughly calculated by means of the data in the tables, supplemented by the geologist's personal knowledge. The excess weights seen at Marmarth (.035) and Miles City (.030) to the north of the Black Hills, notwithstanding the probable presence of over 4,000 feet of relatively light material above the Dakota, and not to mention possible older beds, distinctly predicate the extension to the northward and northwestward of the heavy pre-Cambrian material in probable continuity with the Black Hills mass. If, as seems probable, there is a thickness of 5,000 feet or more of sediments of .22 average deficiency at these stations, this compensates the Marmarth anomaly to +.047; while, if the similarly light sediments under Miles City are not less than 5,700 feet in thickness, the Miles City anomaly will compensate to +.044, or higher. The anomaly (+.032) at Towner will compensate to +.045 or more, if the light Tertiary and Cretaceous rocks at this station exceed 5,000 feet in thickness.

It is thus fairly obvious that very heavy pre-Cambrian, probably continuous with the core of the Black Hills, extends over a large area in western North Dakota and eastern Montana.[65] Some rough computations, which the reader may readily make, indicate probably justified compensations of the Hinsdale anomaly, +.029 to +.038; Poplar,

[65] See W. T. Thom, Jr.: The relation of deep-seated faults to the surface structural features of central Montana. Bull. Am. Assoc. Pet. Geol., vol. vii, no. 1, January-February, 1923; U. S. Geol. Survey Bulls. 471-A, D, and F, 341-A and B, 647, 541-H, 736-D, 711-F and G, 691-D and F, 641-C, 736-B, 621-F and L, 381-B, 316-D, 716-B and E, 702, 656, 452, 661-E, and 581-C; U. S. Geol. Survey, 21st Ann. Rept., pt. 2-D and pt. 3-B, and 19th Ann. Rept., pt. 2-E; Prof. Papers 53, 65, and 108-D, and Geol. Folios 107, 150, 91, 107, and 30.

+.019 to +.034; Huntley, +.011 to +.024, and Rock Springs, where light rocks probably exceed 10,000 feet in thickness, from +.013 to +.037. Huntley may, therefore, for the present, be regarded as lying outside of the region of greatly excessive weight. On the other hand, if the light sediments at Lander aggregate 9,500 feet, as seems probable, with a deficiency in weight of .22, the Lander anomaly, +.019, compensates to +.043, which, together with Rock Springs, would indicate a possible extension of heavy material in the pre-Cambrian floor from the Black Hills southwestward.

The extension of the heavy basement matter beneath the area of deep sediments in northeastern Wyoming and into the Bighorn Mountain uplift is somewhat conspicuously indicated, for at Sheridan, 15 miles from the granite outcrop in the Bighorn Mountain mass, a plus anomaly of .032 is found over a distinctly light sedimentary section very likely exceeding 9,000 feet. Very roughly calculated according to the estimated densities of the strata, this corresponds to about —.015, which compensates the observed anomaly to +.047 and makes it approximately equal to the anomaly on the crown of the Black Hills uplift. In effect, therefore, the pre-Cambrian floor would seem to be of approximately uniform density throughout the region, and the differences between the anomalies in the Black Hills, the Powder River basin, and the Bighorn Mountains are apparently due mainly to the rocks under the stations.

Contrary to the general rule pointed out by Henry Washington,[66] we have in the Black Hills very heavy rocks at high elevation. On the other hand, it may be that the rather widespread heavy matter, which appears to be of regional extent, may lie deeper than the dense rock in the Wichita-Arbuckle zone or the Deer Park arch.

Compensations for light weight of strata at Faith, South Dakota (+.015), and Valentine, Nebraska (+.018), will probably show a decrease in the weight of the crystalline floor in these directions even greater than that noted at Huntley, to the northwestward.

More thorough consideration, with command of more detailed information, is needed for the formulation even of tentative conclusions as to the distribution and effects of unusually heavy basement rocks westward of the area under discussion. At present, however, Rock Springs, Wyoming; Huntley, Montana; Crosby, North Dakota; Faith, South Dakota; and Valentine, Nebraska, may provisionally be regarded as taking part in the definition of the denser portion of this great area of excessively heavy basement. If the excess weight in this region is due to a mass of

[66] H. S. Washington: Isostasy and rock density. Bull. Geol. Soc. America, vol. 33, pt. 2, 1922, p. 398.

great overdensity at very great depth, the greatest excess anomaly should be over the center of the mass and the intensity of influence should gradually fade outward from this point.

No evidence of weight comparable to that beneath the northern Great Plains is yet found in the Nemaha Mountains, or the Ozark uplift, or anywhere east of Lake Michigan.

In the Yellowstone National Park[67] the anomalies seem to be influenced by flows of light weight varying in thickness and lying on varying subjacent sediments or igneous rocks.

Boulder, Montana, located on the Boulder batholith, which is composed mainly of quartz diorite (quartz monzonite), specific gravity probably near 2.68,[68] has an anomaly of —.015.

Again bearing in mind that the effect of the intervening thick columns of sediments in the deep areas is only to reduce the plus anomalies, it becomes apparent that either the northern Great Plains embraces a large region in which abnormally heavy rock lies relatively near the top of the pre-Cambrian surface or, alternatively, the outer crust of the earth is here overloaded. No adjacent or near-by region of great deficiency in weight capable of balancing this mass is indicated on the map showing the present stage of gravity observation. The only comparable areas of corresponding and widespread underloading which might offer compensation would appear to lie in the Ouachita synclinorium and the Appalachian basin. Even in the Northern Great Plains it is more probable that the large plus anomalies are due to heavy matter relatively near the pendulum—not to regional overloading for compensation in some other relatively distant region.

NEMAHA MOUNTAINS TO ROCKY MOUNTAINS

The occasion precludes more than a brief review of the anomalies in the region east of the Rocky Mountains and the Rio Grande, with special comments on a few of the most interesting observations. The results, accompanied by some stratigraphic data,[69] are listed in Table Q.

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[67] U. S. Geol. Survey, Geol. Atlas, Folio No. 30.

[68] Density should be somewhat lower, possibly but 2.58.

[69] U. S. Geol. Survey Prof. Papers 32, 17, 94, 95-C, 101, 54, and 63; Water Supply Papers 215, 216, 12, 184, and 6; Geol. Folios 36, 88, 58, 7, 212, 206, 71, and 68; Bulls. 691-A, 381-C, 285-A, and 57; Monograph 27; 17th Ann. Rept., pt. 2-F; Univ. of Nebraska: Conservation Survey Div. Bull. No. 16, 1923.

TABLE Q

Nemaha Mountains to Rocky Mountains *

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
83	Paxton, Nebr..... 932 M	—.**006** —.005 +.002	Arikaree beds. 2,000± to Dakota; older Mesozoic and Paleozoic (3,000± ?) to granite.
271	Bridgeport, Nebr.....—	—.**008**	Tertiary. Well 6,000 at Harrisburg, 60 miles west. Paleozoic probably present.
41	Wallace, Kans..... 	—.**012** —.009 —.004	In Pierre; 1,300 Cretaceous shale, clay, sandstone, and thin limestone. Well in Pennsylvanian (?) at 2,450. Well near Tweed in lower Pennsylvanian at 3,840.
44	Denver, Colo..... 1638 M	—.**016** —.016 —.008	Thirteen miles to granitic mass of range. 9,500 Denver to base of Dakota; +4,800 base of Dakota to granite.
42	Colorado Springs, Colo. 1841 M	—.**007** +.003 +.001	Three miles east of slightly overhanging (faulted) granite mass of Pikes Peak. 5,400 lower Pierre to base Dakota; +7,300 base Dakota to pre-Cambrian. Sandstone, shale, conglomerate, gypsum, and arkose with not over 500 limestone, mostly near base. Near axis of deep syncline, close to uplifted dense mass.
43	Pikes Peak, Colo..... 4293 M	+.**021** +.045 +.029	Uplifted granites, gneisses and intrusives; mostly Pikes Peak granite (biotite granite, low in feldspar and magnesium) near station; six miles to faulted sedimentary basin.
71	Las Vegas, N. M..... 1960 M	+.**003** +.016 +.011	Well five miles northwest, 3,822 (sandstone, shale, and some thin limestone) Dakota into Magdalena (Pennsylvanian).
100	Guymon, Okla..... 949 M	—.**017** —.016 —.009	Permian; well fifteen miles southwest, 3,040 (shale, sandstone, gypsum, salt, and thin limestone) into "Permo-Carboniferous." Well at Gate, thirty miles east, probably in Pennsylvanian at 3,537.
99	Farwell, Tex..... 1259 M	—.**016** —.013 —.008	Permian red beds; well twenty-five miles east in red beds (sandstone, shale, thin clay, gypsum, salt, and thin limestones) at 3,870. Well twelve miles east in "Permo-Carboniferous" at 3,672.

* Elevations of stations, in meters, are given beneath the names.

TABLE Q—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
61	Sweetwater, Tex..... 655 M	—.029 —.028 —.021	Central Texas syncline. Well fourteen miles northwest =230 Cretaceous +2,020 Permian red beds; in basal Pennsylvanian at 4,250.
63	El Paso, Tex..... 1146	+.007 +.010 +.015	Pleistocene sands probably on Paleozoic magnesian limestone, on granite and cut by intrusives.
98	Alpine, Tex..... 1359 M	+.021 +.034 +.029	"Undifferentiated pre-Cambrian, volcanics and intrusives."
62	Kerrville, Tex..... 500 M	+.031 +.035 +.039	South flank of Llano uplift. Thin lower Cretaceous with possible Paleozoic (2,000±) on schist cut by basic intrusives.

The contrast between the Pikes Peak (+.021) and the Colorado Springs (—.007) anomalies has been emphasized by Bowie and others as illustrating apparent lack of adjustment at two closely located stations. The granites of the peak appear to form part of an overloaded column against which stands one of deficient weight. The two are regarded as too near to be independently compensated; hence both are possibly compensated on a single large block which is presumably in isostatic equilibrium. Granting this, it nevertheless is certain that the weight of the total columns contrasts very much less than the anomalies indicate. The crystalline mass of the Front Range, though in part composed of light types, apparently exceeds 2.67, the assumed average density of the topography, and, besides, is in geometrical figure favorable to exert effective downward pull on the pendulum. The anomaly compares with those of the Piedmont region and suggests that the pre-Cambrian of the Front Range in Colorado is distinctly lighter even than that in the border zone of the exceedingly dense mass embracing the Black Hills and Bighorn uplifts in the Northern Great Plains.

The basin in which Colorado Springs is situated is locally steeply faulted against the granite, from which the gravity station is but three miles distant. The sediments, about 12,000 feet thick, are relatively light, with not more than 500 feet of limestone, mainly in the lower portion. The expectation of a minus anomaly is, of course, realized. That its size is not larger is, however, due no doubt in part to proximity of the heavy igneous matter, which must slope beneath the basin, with its strong downward drag, that is not offset by the excess weight of the topography. Were the station located several miles east of Colorado Springs, the minus anomaly would be larger, unless an anticlinal raise

in the floor produces conditions not visible at the surface. Thus, Denver, similarly placed with reference to the structure, but located farther, about 13 miles, from the crystalline, shows a minus anomaly (.016) more than twice as large as that of Colorado Springs. The latter stands on Pierre shale, while Denver, on the Denver formation, is believed to have thicker sediments beneath, though measurements made from outcrops along the mountain flank are likely to exaggerate the thickness on account of fan and wedge structure.

Post-Denver faulting, possibly mid-Tertiary, has taken place along the foothills in this region. The heavy side has risen.

Confident that isostatic conditions on the crystalline opposite Denver would be comparable to those on Pikes Peak, a station was, in 1917, through the courtesy of the United States Coast and Geodetic Survey, located at Idaho Springs. The anomaly for this station, which stands on biotite-sillimanite schist, with pegmatite granite inclusions in the vicinity,[70] is +.022, almost identical with that at Pikes Peak.

To confirm the apparent relations of these anomalies to the structure, stratigraphy, and relative densities of the rocks in other portions of the syncline presenting similar conditions, the Coast and Geodetic Survey was good enough to locate three stations in profile on the basin farther north. Boulder, in nearly the same stratigraphic position as Colorado Springs, but closer to the crystalline, which, however, is faulted, less bold, and in lower topography, gives —.014; Lafayette, about 55 miles eastward, farther out in the basin, and stratigraphically about 600 feet lower than Denver, gives —.020, while Brighton, nearly 70 miles farther east and on the same beds, shows —.006. The reduced size of the anomaly at the Brighton station agrees with the supposition that a buried uplift, or an anticline, like that found by the drill near Scranton, east of Denver, is present east of Boulder.

The conclusion that the minus anomalies of the Denver basin are due to the great thickness of light sediments beneath the stations is unavoidable. Roughly compensated for conservatively calculated deficiencies in density of the strata, the anomalies become plus and in amounts suggesting that the pre-Cambrian under the axis of the basin may not vary far in density from that in the Front Range uplift.

Preponderant heavy matter in the "granites" farther north in the Front Range axis is, however, shown at Buford, Wyoming, where a station established in 1917 on the Sherman granite batholith[71] gives +.046.

[70] Quartz monzonite and other types of igneous lie within 5 miles.

[71] Coarse-grained, chiefly pink feldspar and glassy quartz, with hornblende and mica; areas of granite porphyry and granite gneiss within three miles. See U. S. Geol. Survey Geol. Atlas, Folio 173.

Quite in contrast with those at Pikes Peak and Idaho Springs, this anomaly approaches the large plus anomalies in the region to the north and raises the question as to a common source of the heavy matter, if not a continuity of body with the Black Hills. It agrees fairly well with Moorcroft, if allowance be made for the thickness and light weight of the sediments at the latter station.

Far to the south of the Denver basin, in the broad syncline of thick "Red Beds" of western Oklahoma and Texas, we find minus anomalies, as might be expected, over the deep sections at Guymon, Oklahoma (—.017), Farwell, Texas (—.016), and at Sweetwater, Texas (—.029), where the "Red Beds" section reaches perhaps its greatest depth. The size of the anomaly at Sweetwater suggests a trough at this point.

In view of the generally light matter in the post-Paleozoic at Las Vegas, which probably stands less than 4,500 feet above the granite, the very small plus anomaly (.003) at this station suggests a density in the pre-Paleozoic rocks somewhat greater than that beneath the Allegheny basin of western New York and eastern Ohio. Intrusive matter may affect the Las Vegas anomaly.

The rather large plus anomalies at Alpine, Texas (.021), and Kerrville, Texas (.031), conform to the relations of these stations to the schists and intrusives about Alpine, and the position of Kerrville on the flank of the Llano uplift.[72] A larger plus anomaly is likely to be found on the core of the Llano uplift.

GULF COASTAL PLAIN AND FLORIDA

General statement.—In considering the results of gravity observations in the Gulf Coastal Plain it is necessary to recall that (1) the region lies low above sealevel, so that maximum errors in the calculation of theoretical gravity may arise from departures of the rock from the assumed average density (2.67) for great depths below sealevel; (2) the region is one of known buried folds, faults, and old topography which, in the light of the foregoing review, are almost certain to affect some of the anomalies, since on the axes of folds or along faults heavy rocks may be brought near the surface in the midst of great thicknesses of very light strata, while deep basins may lie, and in places are actually known to be present, between submerged axes of uplift or ancient topographic barriers, casual lines of weakness, and consequent deformation; and (3) finally, the phenomena of the known features drive the imagination to ultraspeculative limits in the legitimate and necessary formulation of

[72] U. S. Geol. Survey Geol. Atlas, Folio 183; Texas Bureau of Economic Geology and Technology geologic map of Texas, edition 1916.

tentative working hypotheses. The number of unknown quantities, always exasperatingly great, is exceptionally large in the Gulf Coastal Plain and Florida. The considerable increment of hazard is largely tectonic.

The sediments of the Tertiary are mainly sandy clay, sands, clays, gravels, and sandstones, with few limestones except in the Florida peninsula, while the Cretaceous contains more sandy clay, marl, and sandstone, limestone forming a minor portion of the aggregate. In general the latest Tertiary and the thick Pleistocene sediments, which exceed 2,000 feet in portions of the Gulf Coast, Louisiana, and the estuarian areas to the east, are mostly unconsolidated, being comparable to the sediments of the Atlantic Coastal Plain. In the western portion of the Gulf region they are, on the whole, probably even lighter. The older Tertiary is in considerable part consolidated and the Cretaceous is largely so.[73] (See Table R.)

TABLE R

Gulf Coastal Plain and Florida

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
10	Austin, Tex. (Capitol)	—.**008** —.008 .000	Austin chalk under terrace gravels. Possibly 1,200 to Paleozoic or granite.
11	Austin, Tex. (Univer.)	—.**010** —.010 —.002	Eagle Ford under terrace gravels. Minor fault between stations No. 10 and No. 11.
9	Laredo, Tex	—.**020** —.022 —.012	Cook Mountain; 2,500± shale, sandstone, clay, and thin limestones to base of Tertiary +4,000± Cretaceous.
97	Nacogdoches, Tex	—.**012** —.013 —.004	Cook Mountain; 1,406 shale, sandstone, clay, marls and few thin limestones, to Midway at Woden, +550 shale and limestone of Midway. Appleby well, nine miles east = 3,350 in light sediments.

[73] U. S. Geol. Survey Geol. Atlas, Folios Nos. 64, 76, 183; Prof. Papers 46, 90-J, 95-F, 81. 98 L and M, 112, 108-G, 125-D; Bulls. 661-C, F, G and H, 629, 641-D, 212, 213, 260, 282, 429, 283, 736-A, E and G, 715-N, 619, 716-D, 669, 43, and 604; Water Supply Papers 335, 317, 276, 154, 191, 114, 149, 159, 110, 319, 341, 197, 227, and 293; 21st Ann. Rept., pt. 7, and 18th Ann. Rept., pt. 2-B; Bull. Am. Assoc. Pet. Geol., vol. iv, pp. 269-283, 1920; Julius Fohs and Heath Robinson, Structural and stratigraphic data of northeast Texas petroleum areas: Econ. Geol., vol. xviii, no. 8, December, 1923; U. S. Coast and Geodetic Survey Chart No. 1002; Oil and gas prospecting in Mississippi: Mississippi State Geol. Survey Bull. 15, 1919; Bull. Am. Assoc. Pet. Geol., vol. vii, 1923, p. 684; Alabama Geol. Survey Bull. No. 22; Petroleum possibilities of Florida: 14th Ann. Rept., Florida Geol. Survey, July, 1922; Am. Jour. Sci., 4th ser., vol. 44, no. 259, July, 1917, pp. 146-150; and Am. Jour. Sci., 5th ser., vol. ii, 1921, p. 62.

TABLE R—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
73	Denison, Tex.	+.005 +.004 +.013	Flank of buried Pennsylvanian uplift, the Preston anticline. Well two miles north, shows 850 Cretaceous shale and limestone, +1,450 Paleozoic shale, limestone, and sandstone.
8	Point Isabel, Tex.	+.027 +.030 +.035	Well on coast twenty miles east of Brownsville, in sediments of Coastal Plain at 5,220: in Miocene at 4,500. Probably buried igneous of heavy type in vicinity.
7	Galveston, Tex.	—.009 —.008 —.001	Well 1,510 sandy clay, sand, and clay of Pleistocene and doubtful age, +650 upper Tertiary, +770 in upper Miocene; 3,070 in all. Well fourteen miles west =3,500 (2,000 "Pleistocene" +1,500 Miocene).
144	Alexandria, La.	—.006 —.005 +.002	Well 3,190, shale, clay, sand, mostly Pleistocene, in Rapides Parish.
5	New Orleans, La.	—.013 —.010 —.005	About 2,000 Pleistocene and Recent, on Tertiary, etcetera. Should have 7,000+ of generally very light sediments. Anomaly fully accounted for by latter.
142	Texarkana, Ark.	+.011 +.009 +.019	Well 2,985, half mile south, clay, sands, and thin limestone, into Trinity. About 1,400 to chalk. Heavy rocks of Arbuckle-Wichita zone of uplift probably beneath sediments.
167	Arkansas City, Ark.	—.012 —.012 —.004	Deep alluvium plus Pleistocene on Tertiary, etcetera, probably accounts fully for anomaly.
6	Rayville, La.	+.016 +.017 +.024	Near large Monroe anticline. Spyker well No. 1 in Monroe field in shale, clay, sands, and thin limestone, with some red beds; 2,500—3,565 in basal Cretaceous, or Permian?
145	Laurel, Miss.	+.014 +.016 +.022	Catahoula sandstone. Well six miles west of Meridian, in chalk at 3,000. Station is on flank of Arbuckle-Sabine-Hatchetigbee uplift zone.
93	Wilmer, Ala.	—.044 —.042 —.036	Mobile well in Pleistocene at 700; Miocene at 1,500. Wilmer probably in very deep very light sediments south of Hatchetigbee uplift.

The provisional assumptions that Laredo (—.020) is deeply synclinal and that Nacogdoches (—.012) is either on a broad basin or a shallower

syncline appear permissible, though they are based, perhaps, as much on the sign and size of the anomalies as on the known or probable thickness of the sediments or any hypothetical buried structure.

The small minus anomalies at the two Austin stations, which, if the metamorphic floor is as near the surface as calculated, would appear to be exceptional, deserve special attention with reference to the composition and density of the pre-Cambrian and igneous in the general region and to the nature and distribution of the nepheline basalt intrusives. Austin is near the Balcones fault, and deficiency of balance is possible.

Denison, Texas (+.005), is not far south of the axis of a plunging buried fold of Pennsylvanian strata which forms a narrow buried ridge, the northwest-southeast core of the Preston anticline. This anticline is one of several sharp upward flexures of Paleozoic known to be present south of the Wichita-Arbuckle Mountains. In this region of Oklahoma and Texas unusually heavy igneous rocks normally lie buried beneath Cretaceous, Permian, Pennsylvanian, and a very great thickness of older Paleozoic rocks, as will presently be seen. The plus sign of the Denison anomaly is due to this heavy matter.

Arbuckle axis experiments.—To test the effects on the pendulum of one of these folds where rather deeply buried, and to ascertain whether the igneous rocks in the Wichita-Arbuckle uplift zone would produce large plus anomalies, as in the Piedmont and most other regions of eroded pre-Cambrian, several experimental observations were, through the generous cooperation of the Coast and Geodetic Survey, carried on in 1922. First, three stations were located in profile across the main Arbuckle uplift, as follows: Station 300, Wapanucka,[74] on the north flank of the uplift and on the south border of the Ouachita syncline; Station 301, at Troy,[75] on pre-Cambrian granite, near the pre-Cambrian Tishomingo granite mass and about four miles from an area of gabbro, in the heart of the deeply eroded granite core of the Arbuckle Mountains, and Station 302, Idlewilde,[76] Oklahoma, south of the axis, in a deep syncline of steeply tilted shale of Carboniferous age and probably at least 13,000 feet from the granite. On account of the steep inclination of the beds at this station, the vertical distance to the crystalline may be much greater. The lower 7,000 feet of the stratigraphic column consists largely of limestone. Wapanucka, on the Wapanucka limestone, was not well chosen for gravity observation, for while the normal section may directly underlie it, if the pitch of the fault about two miles on the south is not

[74] U. S. Geol. Survey Geol. Atlas, Folio 79.

[75] U. S. Geol. Survey Geol. Atlas, Folio 98; Oklahoma State Geol. Survey Bull. 20, pl. xviii.

[76] U. S. Geol. Survey Prof. Paper 31, 1904, plate I, with cross-sections.

too flat, the older Paleozoic formations, aggregating more than a mile in thickness, are largely faulted out in the upturn, which places a granite mass about two miles from the station.

A value of —.016 for the deficiency of density in the tilted sediments under Idlewilde would appear conservative, while the normal section actually beneath Wapanucka should produce a difference of —.009 or more, most of the limestone being in the lower 6,000 feet of the 11,000-foot section.

The anticipation that a large plus anomaly would be found at Troy and large minus anomalies at Wapanucka and Idlewilde fell far from the mark; the anomalies at all three stations were found to be .020 to .030 dyne larger in the plus direction than was expected. Troy, on the granite complex, gives the remarkable result, +.063, which is the largest plus anomaly yet found in the United States; Wapanucka shows +.020, and Idlewilde —.008. The anomalies show the presence of very dense rocks near the station, in the Arbuckle uplift—apparently heavier even than the heavy cores of the Black Hills and the Bighorn Mountains; or, possibly, matter not so heavy lies much nearer the surface of the pre-Cambrian.

The effects of the great thickness of light sediments on the flanks of the uplift are largely, where not wholly, overcome by the influence of the excessive weight in the Arbuckle axis; yet the Ouachita syncline is so deep and the floor of the Ozark slope so light, as compared with the rocks of the Arbuckle, that a station 20 miles northeast of Wapanucka will probably show a minus anomaly of moderate size; this will almost certainly be the case if the very dense material of the Arbuckle-Wichita zone is essentially longitudinal in its distribution, or if, as I am inclined to believe, it lies comparatively high in the base of the uplift.

The drilling of the Healdton oil field having developed the presence of a narrow ridge of Cambrian or Ordovician (Arbuckle) limestone as part of an old topography buried beneath about 1,600 feet of Permian and Lower Cretaceous sediments, three stations were tested to learn whether the presence of such a buried ridge would be detected by the pendulum.[77] A station, number 303, called Lowery, was located slightly off the crest and on the southern brow of the steep fold where the Arbuckle limestone lay at a depth of about 1,700 feet below the surface of

[77] Contouring of this buried ridge not published. For descriptions of similar ridges see Sidney Powers, The Healdton oil field, Oklahoma: Econ. Geol., vol. 12, 1917, p. 594; Reflected buried hills and their importance in petroleum geology: Econ. Geol., vol. 17, 1922, pp. 244-248; also A. R. Denison, The Robberson field, Garvin County, Oklahoma: Bull. Am. Assoc. Pet. Geol., vol. 7, 1923, pp. 625-637; J. W. Merritt, Pennsylvanian sedimentation around Healdton Island: Bull. Am. Assoc. Pet. Geol., vol. 4, 1920, p. 47.

the nearly flat Permian "Red Beds." The Arbuckle limestone is about 6,000 feet thick at its outcrop on the south flank of the Arbuckle Mountains, and it is not known whether the strata at the top of the buried ridge represent the top or some other level in the formation. Thin Cambrian sandstone separates the Arbuckle limestone from the "granite." Another station, number 305, Busby, about 4½ miles north-northwest of number 303, was placed near a well 2,520 feet deep, ending in Pennsylvanian, while at the third station, number 304, Carter, about 2¼ miles southwest of the first, an apparently normal sequence of Permian and Pennsylvanian was encountered. The regular stratigraphic interval between the base of the transgressing Permian and the top of the Arbuckle limestone in this area can not be clearly determined, but it probably is somewhere in excess of 6,500 feet.

The anomaly at Lowry, on the brow of the narrow uplift, is +.010; that for Busby is —.011. These two anomalies completely fulfilled expectations. Busby, it should be noted, is farther from the buried fold and is located in a basin of deep sediments between the Healdton pool and the Fox-Graham anticlines. In fact, the column of light rocks may be deeper than that at Idlewilde (—.008), besides which Busby is farther from the granite outcrop. Carter shows, however, a plus anomaly (.019) even larger than that on the brow of the buried fold (Lowery) 2¼ miles to the northeast. This interesting result means either a larger or a nearer body of heavy material under or influencing the Carter station. There may be another or more buried ridges not discovered by the drill south of Lowery; "granite" may be less deeply buried here, or it may lie deep in a broader and possibly complex uplift of which the Lowery ridge may be merely a lobe or subordinate fold. Either of these hypotheses is entirely within the limits of possibility and is consistent with ascertained facts, for it is known that farther east such buried uplifts with some faulting occur, one of them, in the Criner Hills, bringing the granite nearly or quite to the Permian surface. Were not such buried folds already known in this zone, which includes the Arbuckle, the Wichita, and the Criner axes, the Carter anomaly itself would excite suspicion.

Since these gravity tests were made, in the summer of 1922, the writer has learned of the application of gravity deflection observations, by means of the Eötvös torsion balance apparatus, to the discovery and mapping of oil field anticlines not only in this region, but in several Old World countries,[78] with reported success. The stations and the results,

[78] W. Schweydar: Die Bedeutung der Drehwage von Eötvös für die geologische Forschung nebst Mitteilung der Ergebnisse einiger Messungen: Zeitschrift für Praktische Geologie, Heft 11, pp. 157-172, 1918; Emanuel Wagner, Prospecting with Eötvös Bal-

probably of much geologic interest and consequence, are at present oil-company secrets.

More stations in the pre-Cambrian of the Arbuckle and Wichita folds are needed to show whether the Troy anomaly is the result of exceptionally heavy rock in the vicinity of the station, and relatively local, or whether it is widespread and characteristic of the uplift zone; also, the gravity relations of this zone to the broader Llanoria[79] should be determined.

Meanwhile the tentative conclusion that the pre-Cambrian of the Ouachita-Arbuckle uplift contains matter of relatively great weight—heavier even than that of the Laramie-Black Hills-Big Horn region of the Northern Great Plains—and very much denser than the Ozark basement seems justified by these observations. The heavy matter of the Arbuckle axis lies abreast of the Ouachita synclinorium, which, at deepest, is believed to contain over 35,000 feet of sediments, and the seeming deficiency in weight of which is indicated by the large minus anomalies of Mena, Arkansas (.052), and McAlester, Oklahoma (.027). These, it will be recalled, are in accord with the comparatively light rock of the Ozark uplift, the long slope of which forms the basement under these two stations. To the extent that the anomalies of these two regions can not be explained or liquidated by the ascertainable variations in weight of the rocks under the instrument—on the heavy core matter of the Arbuckle region on the one side and on the light sediments of the very deep Ouachita syncline and the comparatively light Ozark pre-Cambrian on the other—the two regions may be out of isostatic balance or may take part in a single isostatically compensated mass. Consideration of the effect of position of heavy rock matter comparatively near the surface, and so producing exaggerative effects on the pendulum, in one region or another, is as important as regard for deficiencies of densities of igneous or sedimentary rocks in first determining the extent to which any area actually is over- or under-loaded.

Eastern stations.—I offer little by way of suggestion as to the causes of the signs or amounts of the anomalies for stations in the remaining areas of the Coastal Plain, beyond reminding the reader that in any interpretation of the anomalies for Texarkana (+.011), Rayville, Lou-

ance; Eng. and Min. Journ. Press, vol. 116, October 6, 1923, pp. 583-589; Stephen Rybar, The Eötvös torsion balance and its application to the finding of mineral deposits: Econ. Geol., vol. 18, no. 7, 1923, pp. 639-662.

[79] H. D. Miser: Llanoria, the Paleozoic land area in Louisiana and eastern Texas, Am. Jour. Sci., vol. 2, no. 8, August, 1921, pp. 61-89; C. N. Gould, Crystalline rocks of the plains: Bull. Geol. Soc. America, vol. 34, 1923, p. 541; A. W. McCoy, Short sketch of the paleogeography and historical geography of the mid-continent oil district and its importance to petroleum geology: Bull. Am. Assoc. Pet. Geol., vol. 5, 1921, p. 541.

isiana (+.016), and Laurel, Mississippi[80] (+.014), it is to be remembered that the Arbuckle and Wichita uplifts are in fact axes in a zone of folds, a part of which are buried beneath Permian and Cretaceous immediately to the south; that, extending in an east-southeast direction, this zone passes beneath the Cretaceous, by which it is submerged in southeastern Oklahoma, and that the protraction along strike of this zone of buried folds—lines of ancient weakness—falls under the Sabine uplift, the great Monroe anticline in Louisiana, and the elongated Hatchetigbee uplift in southwestern Alabama. Arkansas City, Arkansas (—.012), and Greenville, Alabama (—.011), lie in the syncline north of this probable zone of uplifts, while Wilmer, Alabama (—.044), falls into a trough on the south. The sediments of this trough are known to be of very light types, but the size of the anomaly predicates a very deep depression.

Buried structure and topography, in part submarine, may be presumed to exert great influence in determining the anomalies of Florida (Table S), in the study of which it should be borne in mind, among other things, that the alinement of the Bahama Islands in series passing toward the Florida coast, and in fact resting on the same landmass, as shown by the configuration of the sea-bottom,[81] is tectonic.

TABLE S

Gulf Coastal Plain—Florida

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
164	Pensacola, Fla.....	—.**014** —.010 —.006	Well 1,607, clay, sandstone, few thin limestones, Pleistocene-Tertiary. Chipley well, 2,500, Chattahoochee into Eocene; in Cretaceous at 3,600; sandy clay of Cretaceous 4,000-4,140.
173	Greenville, Ala.....	—.**011** —.009 —.003	On Midway. Well 2,300 near Selma.
163	Albany, Ga.....	+.**002** +.005 +.010	Near top of Vicksburg; 2,200± sandstone, clay, marls, and rare thin limestones, to basement rocks. Well 1,320, probably near base of Ripley. Cretaceous probably underlain by light Cambrian rocks.
4	Appalachicola, Fla.....	.**000** +.004 +.008	Thick Pleistocene on Tertiary. Well at Burns, 2,153, Chattahoochee to Cretaceous (325), nearly all limestone, much of which is porous.

[80] Mississippi State Geol. Survey Bull. 15, 1919.
[81] U. S. Coast and Geodetic Survey Chart No. 1002.

TABLE S—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
161	Cedar Keys, Fla.	—.021 —.016 —.013	Ocala limestone. Wells to 800. Probably in buried syncline.
160	Leesburg, Fla.	—.014 —.008 —.006	Lower Miocene. Well four miles northeast of Bushnell =3,090, Ocala-Lower Cretaceous (?), nearly all in limestone.
158	Sebring, Fla.	—.017 —.010 —.009	Lower Miocene. Well 1,220; no log.
3	Punta Gorda, Fla.	+.010 +.017 +.018	Caloosahatchee Pliocene. Well at Fort Myers, 2,196, mostly limestone for 950.
1	Key West, Fla.	+.005 +.015 +.013	Key West limestone (Pleistocene); well 2,555, limestone, oolitic, or sandy, for 2,000. Marathon well 1,790; ilmenite grains 180-274; Miocene 180-412; Oligocene 589-984; Cretaceous below 1,248.
157	Homestead, Fla.	—.036 —.026 —.028	Miami oolite (Pleistocene). Well near Miami =1,066, sand, coquina, clay, marls, and thin limestone. Almost surely in syncline.
2	West Palm Beach, Fla.	+.018 +.027 +.026	Palm Beach limestone (Pleistocene). Well at Palm Beach, 1,212, sands, flint, clay, coquina, and some limestone. Probably on uplift.
159	Titusville, Fla.	—.001 +.007 +.007	Pleistocene and late Tertiary. Well three miles south Melbourne 1,250; Eocene limestone below 221. Well near Smyrna, 1,022; Eocene limestone below 105.
92	Fernandina, Fla.	+.010 +.015 +.018	Recent, or late Tertiary. Jacksonville well in Miocene or later, and Eocene and Cretaceous. At Saint Augustine, 1,400, marls, clay, sandstone and limestone (at base).

Salt dome test.—Before passing from the Coastal Plain, three experimental tests at stations on or near a salt dome will be noted. It is reasonably established that the plugs of the Gulf Coast salt domes are extrusive from great depth. Fault structure involving the dome, and in some respects comparable to that long ago urged by G. D. Harris,[82] has been demonstrated by the drill in the vicinity of several of the domes. To determine whether a salt plug is large enough and differs sufficiently

[82] U. S. Geol. Survey Bull. 429, 1910, pp. 6, 7.

in density as compared with the enveloping Pleistocene and Tertiary sediments of the Gulf coast to noticeably influence the pendulum, and to learn whether a buried block or a deep-seated fold would be revealed in the anomalies, three stations were kindly located by the Coast Survey on and near Damon Mound, the largest of the salt plugs, the salt mass being about 1½ miles in diameter and relatively close (about 400 feet) to the surface. The environing sediments, consisting of unconsolidated sands, sandy clays, marls, clays, and gravels, are among the lightest, and are, perhaps, less dense even than those of the Atlantic Coastal Plain.

Station number 312 was placed near the center of the salt plug; number 311 was located about 2¾ miles north-northeast of number 312, in Block number 116, not far from the site of a well which had found nothing unusual at about 3,000 feet. Number 313, 1½ miles southwest of the plug, was placed some distance west of the Ptak well, which was drilled to a depth of 4,624 feet without striking salt.

The anomaly for the salt plug (Station 312) is —.045; Station 311, to the northeast, gave —.034, indicating rather remarkably light weight of thick sediments, or enormous thickness of light weight sediments, while the anomaly for number 313, west of the Ptak well, was found to be —.079, an indicated deficiency exceeded only by the extraordinary Seattle anomalies.

The steep gradient established by the three Damon Mound anomalies points to either a higher level for relatively heavy rock or relatively greater loading on the east; and a profound depth of very light rocks or extraordinary lack of load on the west. The anomalies are compatible with the presence of a deep drop or trough caused by faulting or the overturn of a fold, the eastern limb of which is greatly elevated.

Admitting that the salt is extruded, it would hardly be forced to overcome so great resistance except by powerful lateral thrusts, first forming an anticline, and later presumably overturning the fold before producing the fracture or tearing of the deeper consolidated strata through which the salt might press upward on lines of least resistance. Faulting or overturned buckling beneath the plug is a normal geologic probability. The movement squeezing the salt upward across thousands of feet of strata is possibly post-Miocene. No regional fault passing through Damon Mound has, so far as I am aware, been proved by the drill.

The large size of the anomaly for the station on the east may in part be due to proximity to an underhanging block or adjacent steep trough. However, in the absence of additional information, the size of the anomaly, as well as its sign, is construed as indicating probably great thickness of light sediments on the uplifted side. The anomalies encourage very deep drilling on the east side.

The question as to the distinctive effect of the Damon Mound salt plug on the pendulum remains at present unanswered. Any difference produced by difference in density of the salt and its attendant minerals is masked in the steep gradient from the east to the west. In view of the small diameter of the plug and the close approach between its density (2.14 in the salt core from a similar plug) and the weight of the surrounding sediments, averaging, probably, under 2.16 for 3,000 feet or more, it is not expected that the contrast will be great, though at advanced depth the density of the rocks will be noticeably greater than that of the salt, which may there be of greater diameter, but so distant as to obscure the difference.

Other coast anomalies.—The striking occurrence of a large plus anomaly, .027, at the lighthouse at Point Isabel, Texas, justifies the hypothetical assumption of the presence there of buried dense relief, the elevation of heavy matter in a concealed fold, or the occurrence of igneous matter beneath the station, notwithstanding the drilling near the coast, 20 miles east of Brownsville, of the Espersen well to a depth of 5,220 feet in Coastal Plain sediments, Miocene fossils being found at 4,500. It is observed that the deflections point toward heavy matter along the coast in this vicinity.

In this connection it may not be out of place to record the opinion that the enormous minus anomaly at Seattle, Washington, is due to the great depth of light sediments in the steep-walled Puget trough.[83] Unconsolidated glacial matter, perhaps exceeding a thousand feet, and of very low density, beneath the station is followed by Tertiary sandstones and shales of relatively light weight and of unknown thickness—possibly ten thousand feet and probably somewhat tilted. Beneath the latter may rest still earlier sediments, while the andesites, agglomerates, and tuffs associated with the Tertiary are of light weight. It is germane in this connection to mention a well drilled one mile west of Orting, in which, according to an uncorroborated log, shales, sands, thin limestones, and occasional red beds, representing a series not exposed in the region, were encountered from 800 feet to the bottom, at 2,618 feet. At all events, due allowance for the geological structure and for the character, density, and thickness of the sediments of this region must eventually very greatly reduce if not fully explain the apparent disparity in adjustment at the Seattle station.

Compton, California, Station 66, appears to owe its large minus anomaly (.050) to the great underlying basin of light Tertiary sediments. In fact, the inspection of the anomalies of the Far Western

[83] U. S. Geol. Survey Geol. Atlas, Folio 54.

States encourages the expectation that to a great extent they also may be explained or compensated by abnormalities of weight immediately beneath the pendulum or at high levels in the crust, regard being paid to the tectonic history and structure of the different areas in question.

THE DEER PARK, MARYLAND, ANOMALY

The anomaly (+.010) in the midst of the Appalachian geosyncline, at Deer Park, Maryland, where over 6,500 feet of rather light Devonian shale and sandstone is probably underlain by a thick section of older Paleozoics, deserves special consideration. Believing that the plus sign might result from the relations developed in the formation of the Deer Park anticline, on which the station is located, several collateral tests were, through the courtesy of the Coast Survey, made in 1917. These were number 264, in the Potomac coal basin syncline, at Kitzmiller, Maryland, about eight miles east-southeast of Deer Park; number 263, at Corinth, nine miles west of Deer Park, near the western edge of the lower Youghiogheny Coal Measures syncline; number 262, at Terra Alta, 3½ miles farther west, on the Briery Mountain anticline; number 261, at Rowlesburg, nine miles farther to the southwest, but about five miles across strike, on the Rowlesburg anticline, and number 260, at Clarksburg, about 35 miles west of Rowlesburg, in the main Allegheny coal field.[84]

Kitzmiller lies in a rather deep but narrow elongated and comparatively steep-walled syncline which is continuous with the Georges Creek-Frostburg field. Beyond Rowlesburg the Allegheny coal field extends westward to its outcrop in central Ohio, the center of the upper Pennsylvanian and Permian syncline being in the regions of Pittsburgh, Wheeling, and Charleston, as noted in the discussion of the Allegheny basin.[85] Corinth stands in a little shallow syncline uplifted in a small anticlinorium, less than 20 miles wide, of which the Deer Park anticline forms the east axis and the Briery Mountain anticline the main west axis, with the Rowlesburg anticline as a minor fold on the outer slope of the latter. Deer Park, Terra Alta, and Rowlesburg are at very nearly the same stratigraphic position, in the Chemung a short distance below the base of the Catskill. The thicknesses to the Oriskany, as approximately deter-

[84] For areal, stratigraphic, and structure sections covering Kitzmiller (near Blaine, W. Va.), Deer Park, and Corinth, see U. S. Geol. Survey Geol. Atlas, Folio No. 28; Maryland Geol. Survey reports on Allegheny County (1900) and Garrett County (1902); and for similar data as to Terra Alta, Rowlesburg, and Clarksburg, see reports, maps, and cross-sections of West Virginia Geol. Survey County reports for Preston County (1914), Marion, Monongalia, and Taylor counties (1913) and Goodridge and Harrison counties (1912).

[85] U. S. Geol. Survey Bull. 693, 1919, p. 11; Bull. Amer. Assoc. Petrol. Geol., vol. 5, 1921, p. 609.

mined from outcrops and well logs, including that of the deepest well in the world,[86] are shown in Table T.

The anomaly at Kitzmiller has the minus sign, but is very small, .004, due in part to the long slope of the Deer Park anticline under that side of the basin. A station at Elk Garden near the axis of the syncline and somewhat higher in the "Coal Measures" should show a larger minus anomaly. Corinth, near the western border of the shallow syncline, lying between the crests of the major anticlines, the station being but three miles from Terra Alta, shows a small plus anomaly (.007), but the Terra Alta station, on the Briery Mountain anticline, shows a larger plus anomaly, .010, which duplicates the indicated excess found at Deer Park. The anomaly on the subordinate lateral anticline at Rowlesburg diminishes to +.004. On the other hand, the Clarksburg station, near the eastern border of the main Allegheny basin, shows an anomaly, .006, with the minus sign that is a little larger than that noted above for Kitzmiller, on the eastern side of the Deer Park-Terra Alta arch. It will be remembered that the anomaly at Wheeling, west of Clarksburg, is —.029.

TABLE T

Deer Park, Maryland, Arch

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.	
264	Kitzmiller, Md.	—.004	North Potomac syncline. In Allegheny. Nearly all shale, sandstone, clay and coals to base Devonian.	
			Pennsylvania-Catskill	3,700
			Chemung-Oriskany	6,800
			Silurian	2,500
			Shale, sandstone, conglomerate, clay, and few limestones to top of Ordovician	13,000±
20	Deer Park, Md.	+.010	Near axis Deer Park anticline. Near top of Chemung.	
			Chemung-Oriskany	6,550
			Silurian	2,500 ?
			To top of Ordovician	9,000±
263	Corinth, W. Va.	+.007	In Pennsylvanian on west slope small shallow elevated basin.	
			Allegheny-Catskill	2,050
			Chemung-Oriskany	6,000
			Silurian, if present	2,000+
			To top of Ordovician	10,000±

[86] I. C. White: West Virginia's second deepest well of the world, the I. H. Lake No. 1, No. 4304 of the Hope Natural Gas Company's West Virginia series. The Ohio Gas and Oil Men's Journ., September, 1919.

TABLE T—Continued

Station number.	Locality.	Anomaly.	Local conditions and suggestions or explanations.
262	Terra Alta, W. Va....	+.010	Top of Chemung: on anticline. Chemung-Oriskany ..... 5,700 Silurian, if present ..... 2,000± To Ordovician..... 7,700±
261	Rowlesburg, W. Va.....	+.004	Near top of Chemung, on minor, lateral anticline. Chemung-Oriskany ..... 5,600 Silurian, if present ..... 2,000± To Ordovician..... 7,600±
260	Clarksburg, W. Va.....	—.006	Conemaugh formation, 200 below Pittsburgh coal. Well 7,386, surface into "Corniferous." Surface to Oriskany..... 7,390± Surface to Silurian ..... 8,000± To Ordovician..... 9,800±
207	Wheeling, W. Va.....	—.029	In lower Permian at Washington coal. Heart of the Pennsylvanian basin. Well 4,500, at Big Injun sand at 1,570. Surface to Medina about 6,560. Well in Vinton County, Ohio, 2,500, "Coal Measures" to Medina; +1,225 to Trenton; +625 to St. Peters sandstone.

The difference (.003) between the anomalies at Corinth and Terra Alta or Deer Park is but little greater than would be caused by an added thickness of 2,200 feet, more or less, of rather light sediments (shales, sandstones, coals, clays, and thin limestones), roughly averaging .15 less than 2.67, at the top of the Terra Alta column. On the contrary, the difference between Kitzmiller and Deer Park is greater than is reasonably predicated on a thickening of the section by 4,000 feet between the stations.

Near Clarksburg the interval, including "Coal Measures," to the Oriskany, as determined by deep drilling, is about 7,390 feet, which is less than 1,000 more than the depth of Devonian to the same datum plane at Deer Park. Further, it is rather probable that the underlying Paleozoic section as a whole is thinner at Wheeling, which has minus anomaly .029, than at Clarksburg, which shows minus .006. The difference in the height of the sedimentary columns at Clarksburg and Wheeling, the densities being nearly the same, is, therefore, absolutely inadequate to account for the disparity in the sizes of the anomalies, which roughly corresponds to an interval of 11,000 feet of sandstone and shales,[87] if the

[87] See U. S. Geol. Survey Bull. 693, 1919, p. 11.

average density is 2.48. In fact, the sedimentary column is almost certainly shorter at Wheeling. Wheeling and Parkersburg (—.024) are near the heart of the Pennsylvanian basin and much farther from any known uplift of heavy rocks, including, of course, the Terra Alta-Deer Park arch. The observations, therefore, seem to point clearly to the presence beneath the Paleozoic in the small Deer Park-Terra Alta uplift of matter considerably heavier than that in the same relations to the floor at Wheeling, Parkersburg, or Pittsburgh, or even at Clarksburg and Kitzmiller. On the other hand, the very large minus anomaly (.049) at Hagerstown is an earnest of other minus anomalies to be found in the synclines east of Cumberland. Light basement rocks may confidently be assumed to exist between Deer Park and the Piedmont region, provided, of course, the great differences in the anomalies are not largely due to lack of isostatic balance.

The presence of heavier material nearer to the top of the Chemung in the Deer-Park-Terra Alta uplift may have been caused by (1) the upward transfer, under pressure, of abnormally heavy matter, or magma, to a position, possibly batholithic, relatively higher in the arch, at or following the time of deformation; (2) the existence in this zone of a positive axis or old barrier on which some of the earlier Paleozoic sediments were not laid down and which may have been deeply worn down toward heavy underlying material, and (3) buried pre-Devonian structure or upturned masses of deep-seated rocks. The stratigraphy of the Carboniferous in the vicinity of the Allegheny front in southern Pennsylvania points toward a positive tendency along or near that line.

The seeming restriction of the effect of the excess weight of the rock beneath this small anticlinorium to comparatively narrow zones on either side—that is, its apparent degree of localization in the zone of uplift—points to the higher position of rock matter of moderate excess density rather than the presence of a mass of great density and of great lateral extent at great depth. The Deer Park area, accordingly, seems comparable to the Arbuckle-Wichita zone of uplift and is probably in strong contrast to the great region of excess weight in the Northern Great Plains.

Observation of both gravity and deflection at a considerable number of stations, possibly by methods far more rapid and less costly than the present pendulum procedure, should furnish data by which roughly to calculate the depth, size, and mass of the heavy matter.

HELENWOOD, TENNESSEE, ANOMALY

The genuinely anomalous occurrence of a large plus anomaly (.040) in the midst of nearly horizontal "Coal Measures" on the western slope

of the main Pennsylvanian basin of east Tennessee[88] may, by way of working hypothesis, provisionally be attributed either to the presence of igneous rocks nearer to the surface at this point or to a buried uplift. It can hardly be local. If not local, like a stock or laccolith, it probably extends along strike and at less than eight miles beneath the surface. Additional stations should be occupied and deflection noted.

CONCLUSIONS

From the preliminary review of the local geology and the gravity anomalies at the stations east of the Rocky Mountains in the United States, it appears that:

1. In general, areas of outcropping pre-Cambrian rocks give plus anomalies, especially where they have been subjected to advanced metamorphism or most prolonged erosion. The largest anomalies, indicating greatest excess weight, are found on or near the axes of uplift.

2. Wide variance of indicated weight is observed among the different uplifts and "Azoic" areas, the variation having apparently no definite relation to tectonic activity in recent geologic time.

3. In some areas, such as the Piedmont pre-Cambrian (including "Azoic"), the Deer Park arch, the Arbuckle uplift, and parts of Wisconsin and Minnesota, the influence of abnormally heavy matter is so restricted laterally and so variable locally as reasonably to justify the conclusion that the dense rock material or magma producing the effect of excess weight is relatively high in the uplift or area of pre-Cambrian erosion, with consequently direct and responsible effect on the pendulum. The rock of abnormal density may be local, in which case the anomaly is local.

4. In certain other areas, like the exceptionally dense region of the Northern Great Plains, the heavy pre-Cambrian basement matter may be of regional extent, and possibly deeper, underlying deeply sediment-covered slopes and deeper intermediate synclines.

5. The distribution of plus or minus anomalies is, in general, in close accord with the geologic structure and largely in conformity with tectonic lines.

6. Except in a large area embracing the Black Hills and Big Horn uplifts in the Northern Great Plains, areas of 4,000 feet or more of sediments, including much relatively light material, very generally show minus anomalies, the amount of the anomaly being usually greater where the sediments are thicker and greatest in the deep parts of the deep syn-

[88] U. S. Geol. Survey Geol. Atlas, Folios Nos. 33, 40, and 53.

clines, such as the Appalachian trough, the Allegheny basin, the Eastern Interior basin, and the Ouachita synclinorium. In other words, minus anomalies are characteristically synclinal; the deeper the syncline the larger, in general, the anomaly. Variations from this general rule appear to be determined largely by basement composition and structure.

7. Both the signs and the amounts of the anomalies are, in large measure, at least, controlled by the excess or deficient density of the underlying rocks in the upper crust, and, accordingly, are subject to compensations which, on the whole, will greatly reduce the apparent departures from isostatic balance. The inspection of the anomalies, with brief examination of the local geologic data, encourages the view that the rock materials of excessive or deficient weight causing the principal portion of the anomalies lie relatively near the surface, and that allowance in the computations for such matter would largely liquidate the anomalies. Most of the anomalies may be largely compensated within 25,000 feet; the writer suspects that nearly all are compensated by abnormal densities at depths less than 50,000 feet.

8. It follows that the equilibrium of the crust beneath the gravity station is very much nearer complete than is indicated by the anomalies as uncorrected for local abnormal densities relatively close to the instrument.

9. Study of the gravity anomalies with reference to the local geology should precede the discussion of isostatic equilibrium at any point.

10. Gravity observations are, within limits, applicable to the solution of certain types of problems in historical and economic geology, as well as of those of dynamic geology and tectonics. The development of rapid, inexpensive, and not less accurate methods of gravity and deflection observation should place invaluable means of research within practicable reach of every geologist, greatly extending the effectiveness of his work, while advancing the progress of our science.

Gravity Interpretations, geological Problems

The foregoing discussions are rambling, superficial, and incomplete. The real geophysical and theoretical problems remain untouched. Further, the writer hopes that the quality and amount of ignorance shown by sins of omission in the tables may extenuate some errors of commission. In apology for his transgressions from his proper paleontological pastures into this waving field of dynamic geology, he must plead the long neglect of the rich harvest by its rightful owners, and so the irresistibility of the temptation. He will be more than satisfied, however,

if he has indicated even rudely the possibilities, the deep interest, and the importance of the study of the local gravity anomalies from the geologic standpoint; if he has shown some bearings of gravity observations, as they may be interpreted by the field geologist, on various problems of theoretical, historical, and economic geology; and, finally, if he has proved the absolute need for such studies, adequate as they can be made, in reaching any conclusion, not only as to whether the earth at any locality or throughout any considerable region is in isostatic equilibrium, but as to the character and extent of overweight or under weight of the rocks in any region.

The interpretation of gravity anomalies is the job of the geologist. The task is difficult and time-consuming beyond expectation or even belief, for each station is a problem; but it is more than fascinating and the proceeds will be profitable to geologists and geology. The United States, with its broad and essentially undisturbed basins and large uplift areas, quiescent for long geologic periods, and its regions of active disturbance and present mountain-building, is exceptionally favorable for such studies.

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RELATIONS OF THE BROWNS PARK FORMATION AND THE BISHOP CONGLOMERATE, AND THEIR RÔLE IN THE ORIGIN OF GREEN AND YAMPA RIVERS[1]

BY JULIAN D. SEARS

(*Presented before the Society December 28, 1923*)

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INTRODUCTION

Is the course of Green River across the Uinta Mountains that of an antecedent or a superposed stream? If superposed, on what formation was its course established? These questions have been the subject of lively discussion for half a century, without being conclusively answered. Much interest has been manifested also in two formations of this region, the Bishop conglomerate and the Browns Park formation, the age, origin, and interrelations of which have not been completely understood.

During field-work for the United States Geological Survey in 1921 and 1922 the writer had an opportunity to study the Browns Park formation throughout its entire known area of outcrop, and has become con-

[1] Manuscript received by the Secretary of the Society January 28, 1924.
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vinced that this formation supplies the key to the relations of Green River and the Uinta Mountains.

Before presenting the problems and the proposed solutions, the writer wishes to express his deep obligation to his associates, W. H. Bradley, James Gilluly, and K. K. Landes, for their splendid cooperation in this study and for many valuable suggestions that they have contributed. At all times during the progress of the work ideas have been so freely exchanged that it is impossible to give more specific credit to each man.

Regional geologic Relations

The Uinta Mountain anticline is a broad, flat-topped, east-west fold, approximately 150 miles long and 30 to 40 miles wide, but only the eastern portion of the major arch lies within the area here described (figure 1). The axis of upfolding is continued to the southeastward, however, as the less prominent Axial Basin anticline, on which are the two sharp domes of Cross and Juniper Mountains. The Uinta Mountain-Axial Basin arch is flanked on each side by a great structural basin, the one on the north being known as the Green River basin and the one on the south as the Uinta basin.

The oldest rocks of the region are exposed in the middle part of the Uinta Mountain anticline and in the Cross and Juniper Mountain domes. These rocks consist principally of the "Uinta" red quartzites and sandstones, about 12,000 feet thick, which are possibly of early Cambrian age. Younger Paleozoic and Mesozoic formations make up the flanks of the arch. Eocene formations cover the outer edges and fill the Green River and Uinta basins. In a broad zone along the crest of the eastern half of the Uinta Mountain-Axial Basin arch the Browns Park formation lies on older rocks with angular unconformity ranging from 10 to 100 degrees. The Bishop conglomerate, capping isolated peaks and uplands north of the arch, also occurs in isolated areas high on the southern slope of the Uinta Mountains.

Major Problems

Of the many problems to be found in this region, two stand out with especial sharpness: The first is the origin of the present courses of Green and Yampa rivers, which have carved remarkable canyons in the upfolds without apparent regard for structure or the relative hardness of strata. The second problem deals with the curious attitude of the Browns Park formation, which, though lying approximately on the crest of the Uinta Mountain-Axial Basin arch, has the structure of a well-defined syncline. In seeking an explanation of the second problem—this

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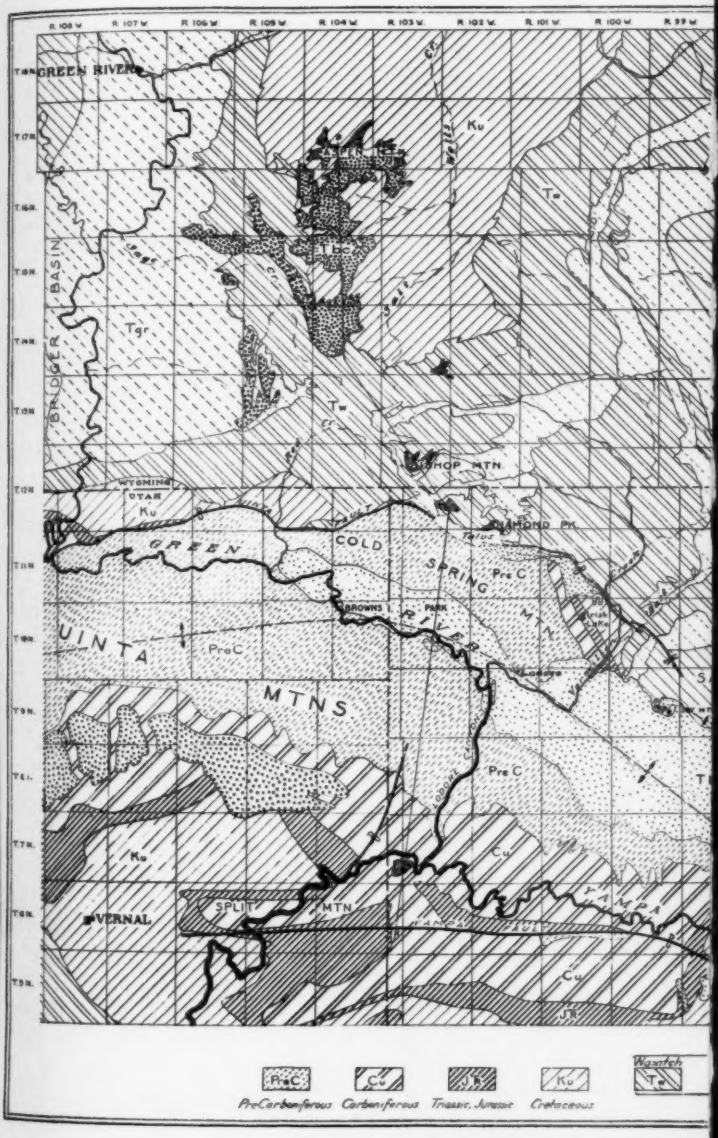

FIGURE 1.—*Geologic Map of the eastern End of*

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—*Geologic Map of the eastern End*

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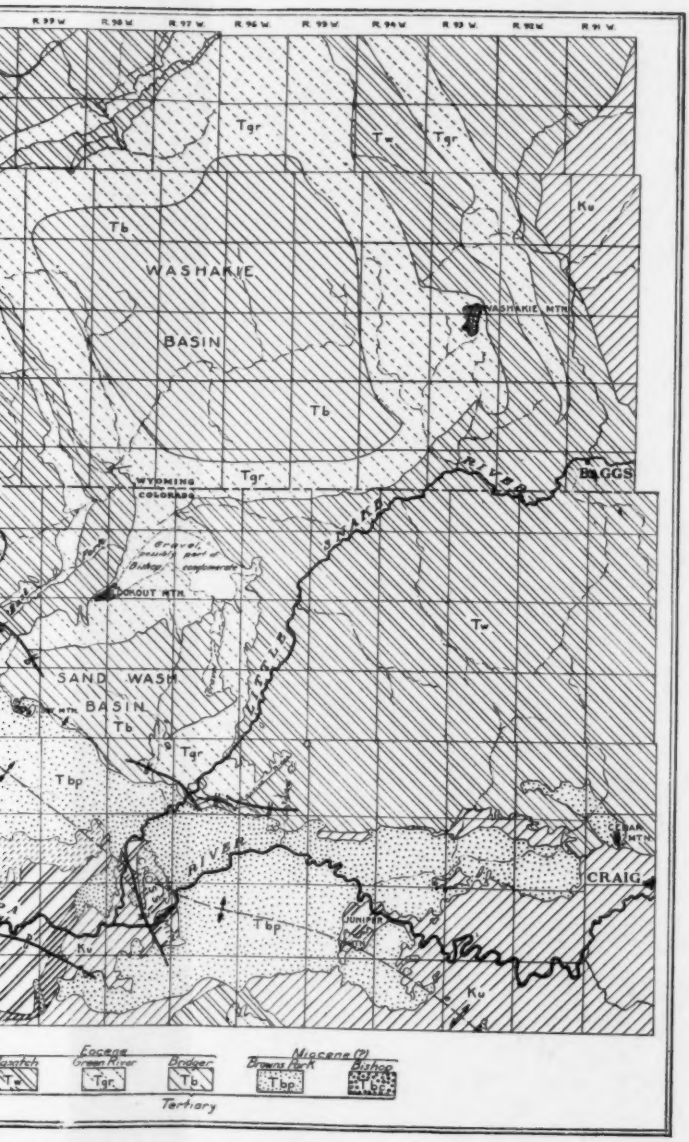

End of the Uinta Mountains and Vicinity

formation and the Bishop conglomerate.

unusual structural relationship—data have been found which the writer believes supply a satisfactory solution of the first problem.

Origin of the Courses of Green and Yampa Rivers

Green River flows southward in Wyoming for many miles on soft, nearly horizontal Eocene beds; then, without deflection, plunges into the north flank of the Uinta Mountains. Southward and eastward its course is through a number of canyons eroded in the hard Mesozoic and Paleozoic rocks which here constitute the mountain mass. From these canyons the river emerges into the open valley of Browns Park. Even here,

FIGURE 2.—*Lodore Canyon*
Looking downstream.

however, it does not keep within the soft sandstones of the Browns Park formation, but makes several detours through spurs of the mountain by short canyons cut in the "Uinta" quartzite. Beyond the park the obvious course of Green River would be a continuation southeastward, through low country and soft rocks, to a junction with the Little Snake, but instead the river swings sharply southward and has cut its way across the main range by way of Lodore Canyon, about half a mile deep in the "Uinta" quartzite (figure 2). The river, after cutting through the main range and being joined by the Yampa, emerges into a synclinal valley, through which it could apparently find an easy outlet westward in soft beds to the lowlands south of the mountains, but instead it again pursues the harder way and crosses Split Mountain by a deep canyon.

The course of Yampa River is no less remarkable. Its intrenched meanders cut in Mesaverde rocks on the north flank of the Axial Basin anticline, its deep canyons through the hard rocks of Juniper and Cross Mountains, and its bold entrance into the eastern end of the Uinta Mountains are more notable because the river apparently could have easily avoided obstructions by a course through low country in soft beds of the Browns Park formation.

The interest of early explorers and later students of this region was keenly aroused by these striking canyons, and numerous attempts have been made to explain their origin. Powell[2] felt sure that Green River is an antecedent stream, and that it maintained its course across the slowly rising arch, "as the saw revolves on a fixed pivot, while the log through which it cuts is moved along." On the other hand, Emmons[3] was convinced that both Green and Yampa rivers were superposed, their courses being established on soft overlying Tertiary formations. Powell's conception was accepted by C. A. White, Le Conte, Geikie, and others; Emmons' theory was adopted by King, Irving, W. M. Davis, and Suess. Modifications have been suggested by other students, but in the main these two theories have formed the basis of all explanations offered. The opposing views have been summarized by Hancock,[4] who also contributes several valuable points in favor of a superposed origin for Yampa River.

The writer is convinced by the reasoning of others and by his own observations that the theory of antecedence is absolutely untenable. It is difficult to picture such an even balance between elevation and erosion that Green River could maintain its course across an uplift of 25,000 feet, including a fault on which, according to Powell's figure, the rocks were upthrown 23,000 feet against the river. Granting that such a balance might persist, nevertheless it seems impossible that the present courses of Green and Yampa rivers were established prior to the deposition of the Eocene beds in Green River basin and of the Browns Park formation on the eastern part of the arch. This deposition would have buried such earlier channels under several thousand feet of sediment, and it seems inconceivable that the rivers could reestablish themselves and cut down to rediscover their original channels at all points. Other reasons which seem to render untenable the theory of antecedence will be brought out farther on in this paper.

There remains the explanation by superposition. If this be accepted,

[2] J. W. Powell: Exploration of the Colorado River of the West and its tributaries, 1875, p. 152.

[3] S. F. Emmons: U. S. Geol. Expl. 40th Par., vol. 2, 1877, pp. 194, 197.

[4] E. T. Hancock: The history of a portion of Yampa River, Colorado, and its possible bearing on that of Green River. U. S. Geol. Survey Prof. Paper 90, 1915, pp. 183-189.

a further question arises: On what formation were the river courses established? It could not have been the Cretaceous beds, as these shared fully in the arching. Only Eocene and later deposits, therefore, need be considered.

The Eocene rocks (Wasatch, Green River, and Bridger formations) must also be excluded as a possible basement. In the first place, at some time after the close of the Eocene the valley of Browns Park was eroded, and later this depression, as well as territory far to the eastward, on the axis of the arch, were buried beneath many hundred feet of the Browns Park formation. No previously established rivers could have maintained their courses across such an area of erosion and deposition. In the second place, the writer believes that the eastern end of the Uinta Mountain arch was never covered by Eocene formations. The fact that no remnant of such Eocene cover has ever been authentically reported is negative evidence for this statement. More positive evidence is that the Eocene sediments of Green River and Uinta basins were derived largely from the Uinta Mountains, and, though connecting eastward around the arch over the site of the present Axial Basin anticline, they overlapped only the outer edges of the main arch. Details of this evidence, which is presented more fully in another paper,[5] may be summarized here. On the north side of the arch the mountainward limit of Eocene deposition is shown in four ways: (*a*) several bodies of conglomerate, with boulders up to six feet in diameter, occur near the mountains in the Wasatch and Green River formations; by their position, lithology, and rapid gradation basinward into fine sediments, they can best be interpreted as alluvial fans; (*b*) distinct overlap and attendant thinning of the Wasatch southward is seen on Vermilion Creek; (*c*) in sections 23 and 24, township 9 north, range 100 west, the Bridger rests directly on Cretaceous and Jurassic rocks, having overlapped the edge of the Wasatch and Green River deposits; (*d*) the Bridger at this locality contains many layers of coarse conglomerate, although notably free from them farther out in the basin.

Possibilities are thus narrowed down to the post-Eocene rocks—the Browns Park formation and the Bishop conglomerate. Emmons[6] believed that the course of Green River was established on the Bishop conglomerate, which at one time covered most of the eastern part of the mountains; Hancock[7] suggested that Yampa River was superposed from

[5] J. D. Sears and W. H. Bradley: Relations of the Wasatch and Green River formations in northwestern Colorado and southern Wyoming. U. S. Geol. Survey Prof. Paper 132-F (in preparation).

[6] S. F. Emmons: U. S. Geol. Expl. 40th Par., vol. 2, 1877, p. 205.

[7] E. T. Hancock: The history of a portion of Yampa River, Colorado, and its possible bearing on that of Green River. U. S. Geol. Survey Prof. Paper 90, 1915, p. 188.

the Browns Park formation. As the Bishop conglomerate has always been considered distinctly younger than the Browns Park, these concepts and the evidence submitted in their support have seemed to be in conflict. The writer proposes to reconcile these conflicting views by showing that the Bishop conglomerate is actually the basal part of the Browns Park formation; that the synclinal attitude of the Browns Park was caused chiefly by deformation; and that the courses of both rivers were established on the Browns Park.

Browns Park Formation

CHARACTER AND SOURCE

The Browns Park formation, named by Powell[5] from its typical exposures in Browns Park, consists predominantly of soft, chalk-white sandstone. Its color, the peculiar lumpy appearance of its weathered

FIGURE 3.—*Basal Conglomerate of the Browns Park Formation*

This photograph was taken in section 1, township 9 north, range 101 west, Colorado.

fragments, and the ease with which it breaks down into loose, deep sand differentiate it sharply from all other formations of the region, except possibly the Nugget sandstone, of Jurassic age, which is distinguished by its remarkable cross-bedding. In general, the Browns Park is well bedded, although cross-bedding is not uncommon, especially east of Cross Mountain. Unequal resistance to weathering of the various sandstone

[5] J. W. Powell: Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, 1876, p. 44.

layers gives the impression of many shale beds alternating with the sandstones; in reality, there is very little clay in the formation. The sandstone is made up almost wholly of well rounded quartz grains cemented with lime. At places west of Little Snake River hard layers of chert and chalcedony occur in the lower part of the formation.

A conglomerate of varicolored pebbles is found at the base of the Browns Park formation east of Little Snake River; it crops out conspicuously north of Yampa River upstream from the Juniper Mountain canyon. Farther west the base of the formation is marked by a conglomerate of red quartzite pebbles and boulders reaching a diameter of two feet (figure 3). This red conglomerate, ranging in thickness from a few inches to several hundred feet, is in striking contrast to the white sandstone above. It is seen almost everywhere along the northern edge of the Browns Park outcrops between Little Snake River and Vermilion Creek, in the outlier of the formation north of Cold Spring Mountain, and also at the northwestern end of Browns Park. Just west of Little

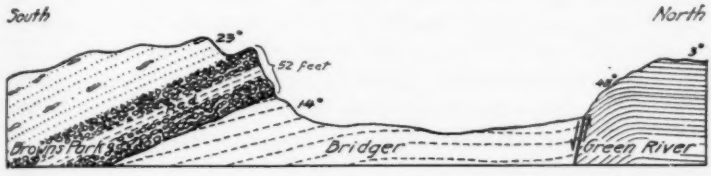

FIGURE 4.—*Sketch Section showing Relations of the Browns Park, Bridger, and Green River Formations west of Little Snake River, Colorado*

Snake River, where the Browns Park formation rests on southward-dipping Bridger beds with a marked angular unconformity, the boulders of the conglomerate are inconspicuous, though the red color is noticeable. At this locality the relations were misunderstood and ingeniously misinterpreted by geologists of the King Survey.[9] Bridger beds, faulted down against Green River shales lying to the north, were thought to underlie the Green River, and hence were called Wasatch. The red conglomerate was described as a band of red shale, and with some of the overlying cherty layers of the Browns Park was also included in the Wasatch. The discordance in dip was explained as an intraformational unconformity in the Wasatch. The true relations are shown in figure 4.

There can be no doubt that the basal conglomerate of the Browns Park formation west of Little Snake River was derived chiefly from the red "Uinta" quartzite. It will be shown that there is also good reason

[9] Clarence King: U. S. Geol. Expl. 40th Par., vol. 1, 1878, pp. 366, 385-386.
S. F. Emmons: Idem, vol. 2, 1877, p. 220.

to believe that the white sand making up the body of the formation had the same source. It has long been recognized that Mesozoic and Carboniferous rocks of the Uinta Mountains furnished the sediments of the Wasatch, and that Carboniferous rocks supplied the material for the Green River formation. Conglomerates of Mississippian gray cherty limestone are abundant in the Bridger near its margin. By Browns Park time erosion had cut down into the great mass of red "Uinta" quartzite forming the core of the arch, and after the outpouring of the coarse material that later consolidated as the conglomerate, further weathering and erosion involved the breaking down and leaching of the quartzite to white sand. Such a color change is unusual, but the red quartzite does today produce just such white sand. At places in the mountains tiny alluvial fans of pure white sand are found where gullies emerge from steep slopes of red quartzite. Boulders of the quartzite show various stages of leaching, the color change passing from red through a dirty yellow to white. Some cobbles were found to be in part yellow and in part the original brick red. Sections of quartzite viewed under the microscope show that the red color belongs to the cement which fills the spaces between the secondarily enlarged white or colorless quartz grains. Another indication of the origin is given by small grains of yellow and brown agate found in the Browns Park at least as far east as Godiva Ridge; these are similar to agates observed in the "Uinta" quartzite of the mountains.

The thickness of the formation is at least 1,200 feet, as shown by measurements east of Vermilion Creek; before erosion it was probably much thicker.

AGE

The age of the Browns Park has long been in dispute and guesses have ranged from Eocene to Pliocene. By various authors the formation has been correlated with the Green River, the Bridger, and the Uinta (all of Eocene age); parts of it have been mapped as Wasatch, Green River, Cathedral Bluffs red beds member of the Green River, Laney shale member of the Green River, and Bridger. Until a discovery by Professor Douglass in 1923, no identifiable fossils had ever been obtained from it. The writer, like all earlier workers, found only certain thin branching tubes which have the appearance of stems or twigs. It can be stated with certainty, however, even without the evidence of fossils, that the formation is younger than the Bridger. The writer has personally traced the contact of Browns Park and Bridger continuously between Little Snake River and Vermilion Creek, a distance of 20 miles. The lithology of the two formations is quite different; the Browns Park lies on the Bridger

with an angular unconformity nowhere less than 10 degrees, and almost all of the way the base of the Browns Park contains its striking red conglomerate. These facts were recognized and clearly understood by Powell,[10] who said: "The unconformity with the . . . Green River and Bridger beds is well exhibited in the Dry Mountains in many fine exposures. . . . Conglomerates are found at the base, in some localities having a great development."

Again, in describing the relations on Little Snake River, interpreted by King and Emmons as an unconformity within the Wasatch, Powell[11] wrote: "The [Browns Park] group is exposed from summit to base, and is seen to rest unconformably upon Bridger beds." It is remarkable that such definite statements should have been generally overlooked, and that so many students have assigned the Browns Park to an earlier date.

In August, 1923, was published a statement[12] that Prof. Earl Douglass had recently made "three very important discoveries of fossils in the Browns Park formation south of Sunbeam, Colorado." These were remains of vertebrates, mostly of carnivorous types. Professor Douglass was quoted as believing the formation to be probably of Miocene age. These fossils were later examined by Mr. O. A. Peterson,[13] who says he believes them to be probably of lower Miocene age, although they may belong to the uppermost Oligocene.

THE SYNCLINAL STRUCTURE AND ITS CAUSE

Through its entire area of outcrop the Browns Park formation (as generally understood) has the structure of a flat-bottomed syncline with sharply upturned edges. Along its southern margin the northward dips range from 3 to 26 degrees; on its northern margin the beds dip southward 6 degrees in the vicinity of Cedar Mountain and reach a maximum of 60 degrees on the southern edge of Sand Wash basin. This attitude is in striking contrast to that of the underlying beds, for the syncline is superposed directly on the crest of the Uinta Mountain-Axial Basin arch. Between the outward-dipping older rocks and the inward-dipping sandstones of the Browns Park, there is angular unconformity ranging from 10 to 100 degrees (figure 5).

During the first season's work in the eastern part of the field no dips greater than 30 degrees and no evidence of post-Browns Park movement were observed. The unusual structure seemed most readily explainable

[10] J. W. Powell: Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, 1876, p. 168.
[11] Idem, p. 44.
[12] Salt Lake Min. Rev., vol. 25, no. 10, 1923, p. 14.
[13] Letter to Mr. T. W. Stanton, November 8, 1923.

as original dip, caused by deposition of the formation on the sloping margins of an old erosion trough. Browns Park itself is clearly such a trough, and its eastward continuation seemed plausible enough, as the formation is bounded by ridges on the north and south. By this conception the upturned edges of the Browns Park would actually mark the original limits of sedimentation.

Later studies showed conclusively that depositional slope could have been no more than a minor factor, possibly sufficient to cause the gentle dips along the south margin and the eastern part of the north margin. For the dips of 30 to 60 degrees, post-Browns Park movement must be

FIGURE 5.—*Pronounced angular Unconformity between the Browns Park and Wasatch Formations*

Photograph taken in section 10, township 7 north, range 96 west, Colorado. Browns Park dips 15 degrees to the right; Wasatch dips 40 degrees to the left. Note also angle between the contact and the bedding of the Browns Park.

invoked, and of such movement there is abundant proof. This late tilting and faulting not only explains the present attitude of the Browns Park, but also furnishes the key for correlating the Browns Park with the Bishop conglomerate; it will therefore be discussed more fully in the section on the equivalence of these formations.

BISHOP CONGLOMERATE

CHARACTER AND SOURCE

The Bishop conglomerate, so named by Powell[14] because of the remnant which caps Bishop Mountain, consists of waterworn and subangular

[14] Idem, p. 44.

pebbles and boulders embedded in a finer gravel and sand matrix. The material is predominantly red quartzite (in part leached to dirty yellow or white) and to a lesser extent gray cherty limestone. Patches of the conglomerate are found high on the south flank of the Uinta Mountains. North of the arch the formation caps several peaks and the ridges and upland sloping gently northward to Aspen Mountain, and also caps Washakie Mountain.

Lithology and distribution show clearly that the conglomerate in this region was derived from the Uinta Mountains. In an excellent paper Rich[15] describes the formation north of the Uinta Mountains as gravel consolidated at the base, loose at the top, and ranging in thickness from 8 to 200 feet; he points out that the conglomerate truncates the structure of the older formations, and concludes that it was laid down on a remarkably even peneplain sloping away from the Uinta Mountains.

AGE

Earlier writers seem to have been unanimous in believing the Bishop conglomerate to be younger than the Browns Park. Doubt may have been implied, but was not expressed, by the statement of Powell that "the Bishop Mountain conglomerate . . . has been found to lie unconformably on all the other geological formations of this region, except the Browns Park, and possibly on the latter also." So far as the writer knows, this view is not supported by any example of undoubted Bishop conglomerate resting on the Browns Park. Such an example may possibly be furnished by boulders of gray limestone scattered over the Browns Park on the Yampa-White River divide, but this is very questionable.

Correlation of the Browns Park Formation and the Bishop Conglomerate

The lack of known Bishop conglomerate resting on the Browns Park merely opens the way for correlating the two formations. Other facts indicate more positively that the Bishop conglomerate is in reality the basal conglomerate of the Browns Park, laid bare by the removal of the soft white sandstone.

In appearance the two conglomerates are practically identical. Both consist almost wholly of red quartzite and contain relatively little of the gray limestone which forms the bulk of the conglomerates in the Eocene formations. Boulders and pebbles in the Browns Park and the Bishop

[15] J. L. Rich: The physiography of the Bishop conglomerate, southwestern Wyoming. Jour. Geology, vol. 18, no. 7, 1910, pp. 601-632.

are well rounded or subangular. The mingling of many sizes indicates lack of thorough sorting during deposition. This lithologic resemblance is so complete that at certain localities it led earlier workers to identify as Bishop a conglomerate that can be definitely shown to form the base of the Browns Park formation, even though they believed the Bishop to be younger than the Browns Park. One instance, in which the apparent error was corrected, is cited by Powell:[16] "There are some conglomerates on the peaks of the Dry Mountains which at one time I believed to belong to this [Bishop] period, but now I think they are of the Brown's Park age." At this locality, in township 9 north, range 100 west, several conspicuous dip slopes of the conglomerate can be traced with certainty under white sandstone of the Browns Park formation.

A second reason for correlation is presented by Green and Yampa rivers. It has already been shown that these rivers must have established their courses on either the Browns Park or the Bishop conglomerate. Let us assume for the moment that the Bishop is actually the younger of the two formations. In this case the rivers could not have established their present courses on (*a*) the Browns Park, for their channels would have been afterward buried by the Bishop conglomerate. Furthermore, if Green River had established its course before the time of the Bishop, it seems impossible to explain the area of Bishop conglomerate mapped by Powell just south of Green River below the mouth of the Yampa. This area is at an elevation of 7,600 feet, the highest point south of the rivers. Assuming that its material is the characteristic red quartzite, it must have been derived from the main outcrops of the "Uinta" quartzite farther north and could not have been carried to its present site across a preexistent canyon of Green River. On the other hand, the present river courses were probably not established on (*b*) the Bishop conglomerate, for in such a case the conglomerate must have covered part, if not all, of the Browns Park formation. It is hardly conceivable that, if this had occurred, no trace of such a cover would remain. Thus the assumption of difference in age leads to a dilemma which can be easily escaped by considering the Bishop conglomerate as the base of the Browns Park.

The third and most important line of evidence for the correlation of the Browns Park formation and the Bishop conglomerate involves the post-Browns Park movement which, as already stated, caused the synclinal attitude of the formation. At first sight the greatest obstacle to correlation seems to be the present marked difference in elevation of the two formations. The surface of the Browns Park ranges from 5,200 feet

[16] J. W. Powell: Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, 1876, p. 170.

along Green River to about 7,800 feet in the valley just south of Diamond Peak. The Bishop conglomerate is between 9,000 and 10,000 feet above sealevel on Diamond Peak and Bishop Mountain, and slopes gently northward to an elevation of 7,600 feet near Aspen Mountain. This discordance of elevation is probably the main reason that led Powell and others to consider the Bishop conglomerate and the Browns Park formation of different ages. The difficulty disappears and the correlation is given greater weight by an analysis of the deformation and paleophysiography before and after Browns Park time. Powell advanced the theory that after Browns Park deposition the eastern end of the Uinta Mountain arch collapsed and a graben was formed on its crest. Additional proofs of this movement have been gathered, and the writer is convinced that by the collapse of the arch the two parts of the Browns Park formation were brought to different levels. Data on which this conception is based may be outlined as follows:

(1) The south flank of the arch is cut by a great fault, nearly 50 miles long, extending from the eastern end of the uplift westward to and beyond Green River. This was called the Yampa fault by Powell,[17] who says that the rocks on the north side are downthrown from 3,000 to 5,000 feet. The Yampa fault marks the southern edge of the graben.

(2) The west side of Cross Mountain is cut by a north-south fault, with downthrow on the west, which brings Mancos shale against the Carboniferous. Browns Park beds in the angle between Yampa and Little Snake rivers have been mapped by Schultz as stopping abruptly against this fault, showing it to be, at least in part, of post-Browns Park age. This fault seems to mark the eastern edge of the main downward movement. Between the eastern end of the Uinta Mountain arch, Cross Mountain, and the Yampa-White River divide the lower surface of the Browns Park slopes gently northward, owing either to deposition on a sloping surface or to warping into the graben. The basal conglomerate in this vicinity consists mostly of gray limestone boulders.

(3) Eastward from Cross Mountain the effect of the graben movement seems to have been a gentle westward tilting of the Browns Park formation. Although the Browns Park in this area is thought to be derived from the Uinta Mountains, its lower surface now slopes gradually westward, from elevations of 6,800 feet at Cedar Mountain and 6,000 feet at Juniper Mountain to an elevation of 5,000 feet in Browns Park.

(4) Along the northern edge of the Browns Park outcrops, between Cedar Mountain and Sand Creek, that formation dips gently southward. Between Sand Creek and Vermilion Creek the southward dips are much

[17] Idem, p. 208.

steeper, reaching a maximum of 60 degrees. The edge of the Browns Park here lies along the southern border of a zone of disturbance that affects the Wasatch, Green River, and Bridger formations. This zone consists of a number of anticlinal axes and faults *en échelon,* which show unmistakable downward movement on the south side into the graben. The Browns Park, with its basal red conglomerate, ends in northward-facing escarpments; it approaches closely, but at no place crosses, the anticlinal axes or faults. As the Browns Park forms the ridge, and the Eocene beds to the north in Sand Wash basin are at a lower elevation, these escarpments can not mark the edge of deposition which stopped short of the zone of disturbance. The only possible explanation seems to be that the region to the south was depressed after Browns Park time, and that the soft Browns Park beds north of the zone, left at a much higher elevation, have been entirely eroded.

(5) Farther northwest, toward Vermilion Creek, the Browns Park lies on successively older formations, from Cretaceous down to Pennsylvanian. The older rocks dip about 30 degrees northeast; the Browns Park dips 13 degrees southwestward into the graben. Along the contact in this vicinity the soft white sandstone of the Browns Park formation has been generally eroded, and the basal conglomerate, which at places reaches a thickness of several hundred feet, forms a conspicuous dip slope. The surface of this slope is approximately parallel to the surface on which the conglomerate was laid down. Half a mile east of Vermilion Creek the dip slope ends abruptly and the contact swings sharply downstream with the dip. Northwestward, however, the old surface, on which the conglomerate was deposited and from which it has only recently been almost completely removed, continues for several miles as a terrace sloping *toward* the mountain and truncating the edges of the resistant Park City formation and Weber quartzite. This striking topographic feature is shown in figure 6. Still farther northwestward the terrace is interrupted for a mile or two by higher edges of the Park City formation, which must have stood above the general terrace level at the time of its erosion. Beyond this, near Irish Lake, the terrace is resumed, but the surface is practically level instead of sloping toward the mountains. A mile farther northwest the terrace is thickly covered with the red conglomerate of the Browns Park, which here forms a notable dip slope northeastward, *away* from the mountains, and passes northward under white sandstone of the Browns Park formation. This curious terrace is interpreted as the mountainward edge of an old peneplain, most of which has been destroyed by erosion. Its original slope was northeastward, but

southeast of Irish Lake it has been twisted and given a southwestward slope by the collapsing of the Uinta Mountain arch.

(6) The outlier of the Browns Park north of Irish Lake extends northwestward around the flank of Cold Spring Mountain, to the head of the creek south of Diamond Peak. Its northern edge is at or near a large fault which extends from East Fork of Vermilion Creek to the southern slope of Diamond Peak. The westward extension of this fault is obscured by debris from Diamond Peak, but most probably it connects with the great Uinta fault, which reaches far westward into Utah. If not continuous, at least the faults are alike in having their planes nearly

FIGURE 6.—*Terrace truncating the Park City Formation and the Weber Quartzite*

View taken westward, on the northeastern flank of the Uinta Mountain uplift. Upper canyon of Vermilion Creek in right foreground; Irish Canyon, through Mississippian limestone of Cold Spring Mountain, in center background; remnant of basal conglomerate of the Browns Park formation on edge of terrace in left foreground.

vertical and the rocks on the south side upthrown. Powell estimated that the throw of the Uinta fault is 23,000 feet. Some of this, as indicated by the mapping of Schultz,[18] must have been post-Wasatch. The fault southeast of Diamond Peak must be also in part later than Wasatch. Mesaverde and Mancos, south of the fault, are brought against Wasatch north of it, and both sides are dragged sharply to a vertical or even much overturned position. For the sake of simplicity, the latter fault will in this paper be treated as the southeastward extension of the Uinta fault.

Relations of the Browns Park formation to the Uinta fault are ab-

[18] A. R. Schultz: Oil possibilities in and around Baxter basin, in the Rock Springs uplift, Sweetwater County, Wyoming. U. S. Geol. Bull. 702, pl. 1, 1920.

normal. If correctly interpreted, these relations form an important link in the evidence for a graben. Powell[19] suggested that after Browns Park deposition a great reversal occurred along the line of the Uinta fault, by which the rocks on the south side fell 3,000 feet. With this conception the writer is in perfect accord, although part of Powell's reasoning was based on an erroneous identification of colored clay shale at the base of the Wasatch (north of the fault, in township 11 north, range 101 west) as "Flaming Gorge" (at least in part Morrison).[20] From this it may be concluded that the basal conglomerate of the Browns Park south of the fault and the Bishop conglomerate north of it were once a continuous layer, and that the present difference of elevation is due entirely to later movement. Proof of reversed movement on the Uinta fault is, therefore, very important.

In section 1, township 10 north, range 101 west, the dip slope of the basal conglomerate of the Browns Park (already described as the north-

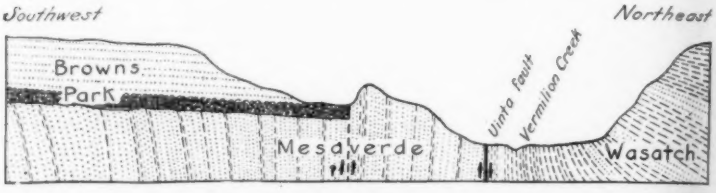

FIGURE 7.—*Sketch Section showing basal Conglomerate of Browns Park Formation resting on and ending laterally against steeply dipping Mesaverde Sandstones*

View is on Vermilion Creek, Colorado.

ward extension of the terrace seen at Vermilion Creek) is covered with detached areas of the white sandstone. It dips gently northeastward and truncates the vertical Mancos and Mesaverde beds. Several hundred feet from the main Uinta fault, which is here concealed by alluvium of Vermilion Creek, the conglomerate stops abruptly against a low ridge of vertical Mesaverde sandstone. This curious relation, which is observable at intervals for a mile and a half to the northwest, is shown diagrammatically in figure 7. Overlap must be ruled out as a possible explanation, as the surface on which the conglomerate was laid down slopes evenly northeastward into the sandstone ridge. If the Mesaverde sandstones had existed as a hogback at the time of deposition, previous erosion would have taken the form of a strike valley on the mountainward side

[19] J. W. Powell: Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, 1876, p. 205.

[20] Idem, p. 206.

of the hogback, and the slope near the ridge would have been away from the ridge, not toward it. The surface of erosion was instead a sloping peneplain, and the abrupt ending of the Browns Park and of the old erosion surface on which it lies may be considered as proof of the reversed movement on the Uinta fault. The line of termination marks the plane of the reversed fault, which at this locality does not exactly coincide with the original fault-plane. The absence of drag in the Browns Park formation at this locality may be explained by its position over the edge of hard Mesaverde sandstone. As the new slipping must have occurred practically along the bedding of the Mesaverde, the hard layers would move as a block and overlying horizontal beds would not be

FIGURE 8.—*Intraformational Unconformity in the Browns Park Formation*
The view is northwest of Ladore Post Office, Colorado

subjected to twisting. Farther northwest the Browns Park near the fault lies on Mancos shale, which was much more distorted by the reversed movement. Here the Browns Park shows distinct drag, the southward dip in one case reaching 60 degrees.

At several localities west of Diamond Peak additional instances of drag caused by reversed movement have been noted by Powell[21] and Reeside.[22]

(7) Not all of the downward movement on this side of the graben took place on the Uinta fault. During the collapse of the arch there was distributive faulting and movement through the mass of "Uinta" quartz-

[21] Idem, p. 206.
[22] J. B. Reeside, Jr.: Personal communication, 1923.

ite in Cold Spring Mountain. Some of these faults may be seen where they cross Bull Canyon, at the southeastern end of the mountain. Their throw must be to the south, as at several places on the southern slope of Cold Spring Mountain the quartzite dips distinctly southward, contrary to the normal dip on the flank of the Uinta Mountain arch. On the north side of Browns Park (valley), northwest of Ladore Post Office, the white sandstone of the Browns Park formation dips 25 degrees to the south, but flattens a short distance out in the valley. In sections 7 and 18, township 10 north, range 102 west, this tilting of the Browns Park formation may be resolved into two stages. The basal part of the formation, several hundred feet thick, containing much chert and chalcedony, dips 23 degrees to the south; the upper portion, consisting almost wholly

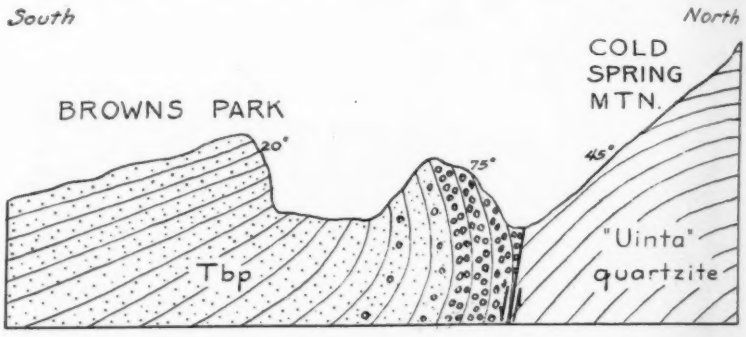

FIGURE 9.—*Sketch Section of a post-Browns Park Fault on the north Side of Browns Park near its upper End*

T b p = Browns Park formation.

of fine-grained white sandstones, dips only 7 degrees and truncates the lower portion (figure 8). This intraformational unconformity and the variation in lithology may be the reason why several earlier writers assigned all of the southward-dipping sandstones on the north side of Browns Park to the Green River. The unconformity, however, seems to be only local, as a mile southeastward along the outcrop no trace of it could be found. Moreover, at other places, especially on Little Snake River, the lower part of the Browns Park above the basal conglomerate contains similar layers of chert and chalcedony.

A fault on Cold Spring Mountain, with downthrow on the south, may also be seen at the upper end of Browns Park. The Browns Park beds have been dragged sharply upward, and the basal red conglomerate is exposed, as shown in figure 9.

(8) The present attitude of the Bishop conglomerate is in itself evidence for the collapse of the Uinta Mountain arch. From an elevation of nearly 10,000 feet on Diamond Peak the conglomerate slopes northward to an elevation of 7,000 feet near Aspen Mountain (shown diagrammatically in cross-section, figure 10). Granting that the conglomerate was laid down on an even peneplain sloping away from the Uinta Mountains, as suggested by Rich,[23] obviously this peneplain at the time of deposition must have extended southward and southwestward, with increasing elevation, to connect with outcrops of "Uinta" quartzite that were the source of material. If Cold Spring Mountain was the source, it must have stood at a higher elevation than Diamond Peak, so as to give the necessary gradient for transportation. If the main portion of the Uinta Mountains was the source, Cold Spring Mountain must have had an elevation intermediate between that of the main range and that of Diamond Peak, so as to form part of the slope down which the material was carried. Yet if the pre-Bishop surface is restored by projection southward from Diamond Peak, it is found to pass nearly 2,000 feet above the crest of Cold Spring Mountain, which has a maximum elevation of 8,500 feet. By what means has the present low elevation of its crest been caused? Erosion is dismissed without hesitation, for it is scarcely conceivable that nearly 2,000 feet of hard, cherty Mississippian limestones and red "Uinta" quartzite on Cold Spring Mountain could have been removed, while the soft Eocene beds of Diamond Peak, protected only by the cap of Bishop conglomerate, were practically untouched. In this statement the writer takes issue strongly with Rich,[24] who cites these differences of elevation to support his theory of the resistance of gravel to weathering. In his earlier paper[25] Rich admitted the possibility that the differences were due to downthrow

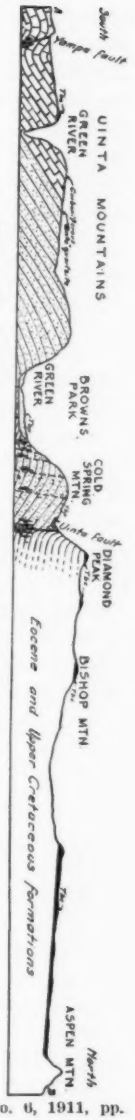

FIGURE 10.—Geologic Cross-section from the Yampa Fault to Aspen Mountain

[23] J. L. Rich: The physiography of the Bishop conglomerate, southwestern Wyoming. Jour. Geology, vol. 18, no. 7, 1910, pp. 608-613.

[24] J. L. Rich: Gravel as a resistant rock. Jour. Geology, vol. 19, no. 6, 1911, pp. 503-504.

[25] J. L. Rich: The physiography of the Bishop conglomerate, southwestern Wyoming. Jour. Geology, vol. 18, no. 7, 1910, pp. 622-624.

by faulting, but said: "This fault is described [by Powell] as displacing beds of the Browns Park Tertiary; but since these beds have been considered to be of earlier age than the Bishop conglomerate, there is no evidence to indicate the exact time of the displacement, whether before or after the development of the conglomerates." Inasmuch as evidence is now at hand to show post-Bishop movement on the fault, dropping of Cold Spring Mountain as part of the collapsing arch seems to be the logical and almost unescapable explanation.

(9) The terrace near Vermilion Creek, as already said, is interpreted as the remnant of a peneplain on which the Browns Park was deposited. According to the statement in the preceding paragraph, it is also the edge of the peneplain on which the Bishop conglomerate was laid down. (It seems unlikely that two stages of planation occurred; that by a coincidence one peneplain would stop and the other begin at the zone in which post-Bishop faulting may readily be postulated; or that simple erosion could account for the significant fact that today no Browns Park is found north of this zone and no Bishop conglomerate is found south of it, on the northern flank of the mountains.) If this reasoning is accepted, it follows (*a*) that the south side (with the known basal conglomerate of the Browns Park formation of the terrace now at elevations of 6,800 to 7,800 feet) has dropped about 2,500 feet below the north side (with Bishop conglomerate at about 9,900 feet on Diamond Peak); (*b*) that Cold Spring Mountain before subsidence must have stood at a relative elevation of at least 11,000 feet; and (*c*) that this mountain, against which the peneplain terrace ends, was the source of most of the conglomerate in this vicinity.

Additional Evidence for Superposition from the Browns Park Formation

There remain to be considered two cases in which superposition from the Browns Park is directly indicated. The first case has already been mentioned. At two places in Browns Park the river swings southward out of the white sandstone and makes detours through short canyons in the "Uinta" quartzite. It seems obvious that these meanders were developed on the Browns Park when the surface of that formation reached a much higher elevation in the valley than it does at present.

The second case is that of Irish, Bull, and Vermilion canyons, at the eastern end of Cold Spring Mountain. The relations of these canyons will be made clear by reference to the detailed map, figure 11. Irish Canyon is largely a strike valley in pre-Weber Pennsylvanian rocks. At the northern end it opens into the low area around Irish Lake by a gap

through the Weber quartzite and Park City formation; at the southern end it swings sharply southwestward and cuts through the Mississippian limestone and "Uinta" quartzite. Between Irish and Bull canyons the stream channel crosses an open valley in sandstone of the Browns Park formation, separated from Vermilion Creek by a very low divide. Bull

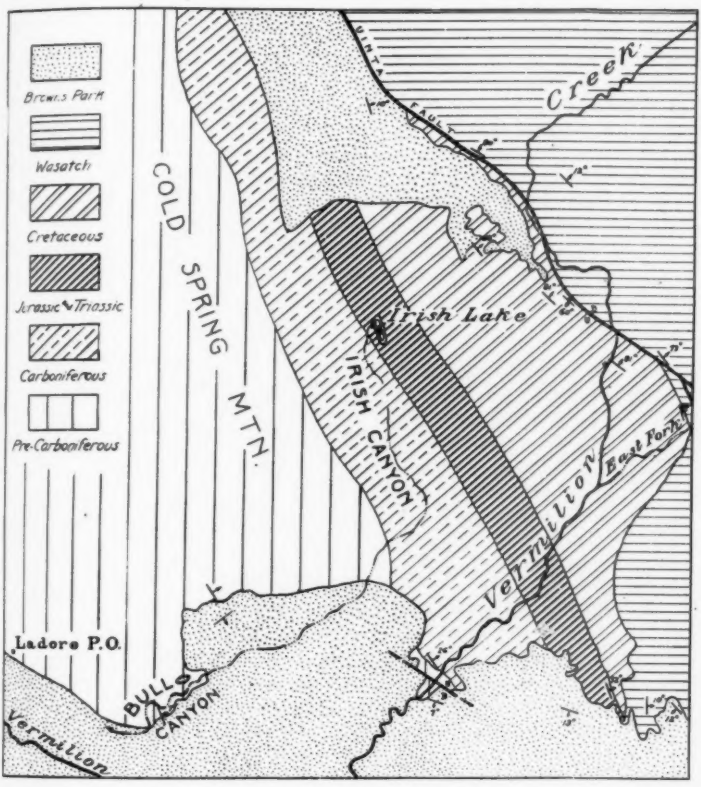

FIGURE 11.—*Detailed Map showing Relations of Irish and Bull Canyons to the present Course of Vermilion Creek*

Canyon is a series of notable entrenched meanders in the "Uinta" quartzite. These meanders undoubtedly originated on the sandstone of the Browns Park, which still lies above the quartzite on both sides of the canyon (figure 12). Vermilion Creek flows southwestward through the Wasatch until it reaches Cretaceous rocks; here it is diverted southeast-

ward for two miles, until it turns once more and, joined by East Fork, crosses the whole series of Mesozoic and Paleozoic strata *against* the dip, finally reaching the Browns Park beds. Its course is marked by two canyons. The larger canyon, about 800 feet deep, is cut through the

FIGURE 12.—*Entrenched Meanders in Bull Canyon*

The red "Uinta" quartzite is overlain unconformably by white sandstones of the Browns Park formation.

Park City formation and Weber quartzite. The upturned edges of these formations are truncated by the terrace already described, from which the basal conglomerate of the Browns Park apparently has only recently been partly eroded. The relative position of this terrace and of the Browns Park formation, which now rests on the older rocks on both sides

of Vermilion Creek, point unmistakably to a once continuous cover of Browns Park on which the stream first cut its channel.

Another interesting feature of the Vermilion Creek drainage is its illustration of stream piracy. The writer believes that at one time the main stream ran through Irish and Bull canyons, and that later it was beheaded by a branch of East Fork. The bottom of Bull Canyon is somewhat higher and Irish Canyon is several hundred feet higher than the bed of Vermilion Creek. The present channels in Irish Canyon are not those of streams which could carve such a type of valley, and the northern end of the canyon now drains into the interior basin around Irish Lake. Furthermore, Vermilion Creek in its course through the Wasatch heads straight for Irish Canyon, but turns aside where it meets harder rocks. Between this bend and Irish Canyon the position of the old channel is indicated by a wind gap and a reentrant in the conglomerate of the Browns Park formation. In this piracy post-Browns Park tilting was probably an important factor. This tilting was partly the movement shown by the slope of the terrace and partly an inclination toward the southeast, shown by local southeastward dips of the Browns Park between Irish and Bull canyons as compared with the normal southwestward dips elsewhere along its northern contact. Other factors, such as the northwest-southeast strike of the older rocks and the relations of hard and soft strata, helped to permit East Fork to lower its channel more rapidly and by headward erosion of a branch to tap Vermilion Creek above its entrance into the hard rocks.

Summary of geologic History

The geologic history of the region, based chiefly on the evidence presented in the foregoing pages, may be summarized as follows:

Many thousand feet of sedimentary rocks were laid down with practical conformity through Paleozoic and Mesozoic time. After the close of the Cretaceous the Uinta Mountain arch was uplifted many thousand feet, partly by folding, partly by faulting. Vigorous erosion of the arch during and following the uplift supplied material for the extensive Eocene deposits which filled the Green River and Uinta basins, united around the eastern end of the Uinta Mountain arch, lapped over the outer edges of its flanks, and probably covered the somewhat eroded crest of the low Rock Springs anticline. At some time after the close of Eocene deposition the Uinta Mountain arch was further uplifted. This second movement, though probably of less displacement, covered a wider area, and the axis of the Uinta Mountain arch was continued far southeastward as the Axial Basin anticline. The Eocene strata, which, of

course, shared in this movement, are now found dipping away from the folds. At this time or possibly a little later the Axial Basin anticline was further deformed by the sharp domes of Cross and Juniper Mountains.

A long period of quiescence followed, during which the eastern Uinta region was eroded to mature topography. Mountains and ridges were comparatively low and the total relief probably did not exceed 3,000 feet. Strata on the southern flank of the Uinta Mountain arch were beveled; on the opposite side a broad peneplain stretched northward from the eastern part of the arch and from the Axial Basin anticline, truncating Eocene and older rocks and perhaps merging with the peneplain on the southern flank of the Wind River Mountains, described by Blackwelder.[26] Owing to higher elevation or to fracturing, the crest of the Uinta Mountain arch was subject to more rapid erosion, and there began the carving of the great intermontane valley of which the lower part is now known as Browns Park. The headward extension of this valley far beyond the present limits of the park is indicated by the terrace above the canyons of Green River upstream from the park and by the westward continuation of the cliffs that mark its south wall. Browns Park valley opened eastward across the site of Dry Mountain and merged with the northward-sloping peneplain, from which it was separated farther west by a low range of hills. High on the south flank of the arch was a similar but lesser valley, the "Summit Valley" of Powell,[27] that drained eastward and probably turned southeastward along the line of the present Lodore Canyon. The Axial Basin anticline was deeply eroded and Cross and Juniper Mountains were left as isolated masses of much the same appearance as they have today.

Climatic changes or, more probably, regional uplift caused a rejuvenation of the streams, which began a vigorous attack on the red quartzite core of the Uintas. Some material was carried from the eastern part of the arch, and the Browns Park valley was greatly deepened; more was brought from the higher western part of the range. There resulted a great outpouring of red quartzite boulders, which were laid down as conglomerate eastward to Little Snake River and northward for many miles over the broad peneplain. On the south flank of the arch the hollows were filled and the beveled surface was partly covered. As time went on, streams lost some of their carrying power and brought white sand derived from the quartzite. Browns Park became filled with a great thick-

[26] Eliot Blackwelder: Post-Cretaceous history of the mountains of central western Wyoming. Jour. Geology, vol. 18, no. 3, 1915, pp. 193-207.

[27] J. W. Powell: Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto. Atlas, Map A, 1876.

ness of this sand, which spread up the valley by headward overlap beyond the earlier deposits of conglomerate. Overlap also gradually covered the slopes of the hills and mountains eastward to and including Cross and Juniper Mountains, until in all the eastern part of the Uinta Range only the highest remnants of the older rocks protruded above the cover of white sand.

If this period of deposition had been succeeded by further arching or by regional uplift, drainage would have followed the same directions if not the same channels, as before, and the conglomerate and sandstone would have been largely swept away by rejuvenation of the streams that made them. In Browns Park time, however, tilting on the south side of Cold Spring Mountain served as the forerunner of a new type of movement, and after deposition was complete the eastern end of the Uinta Mountain arch collapsed, forming a great graben. The collapse was caused by a single large fault on the south, by flexures and distributive faulting on the north, by tilting and some faulting on the east, and by tilting on the west. Along the margins of the graben the Browns Park formation was given an inward dip by upward drag on the faults. As far east as Cedar Mountain, the Browns Park formation was tilted westward toward the drag syncline which lies just north of the Yampa fault. Guided by this sloping surface and this syncline, the drainage of the Axial Basin anticline naturally formed a westward-flowing major stream—Yampa River. Its course over the covered portions of Cross and Juniper Mountains was accidental.

The eastern part of the Uinta Mountains had previously stood at a lower elevation than the western part. By collapse, this difference was greatly increased, and a vigorous stream, the young Green River, began its eastward course approximately above the old Browns Park valley. A northward turn was barred by Cold Spring Mountain and by fault-scarps on the north side of the graben. The river may have continued southeastward to the end of the arch, there turning southward in the syncline west of Cross Mountain to join the Yampa. In this case Lodore Canyon may be due to headward erosion and piracy by a stream which ran southward in the slight depression left after filling of the lower portion of Summit Valley. On the other hand, if the white sandstone was thick enough to cover the site of Lodore Canyon, Green River may have originally turned southward along this line, being diverted by the westward tilt of the Browns Park formation. The thickness of sandstone needed to cover Lodore Canyon seems to argue against the second possibility, but the entrenched meanders of Lodore Canyon and the topography in its vicinity point to superposition rather than to headward erosion.

North of the graben the streams flowed down a northward-sloping surface of Browns Park sandstone, in time cutting to the basal conglomerate of that formation, which covered the old peneplain. They may have drained into a river which skirted the edge of the peneplain in the low ground, where it merged with the peneplain on the southern flanks of the Wind River Mountains. Owing to low gradient and the fact that these streams were running on dip slopes, erosion was comparatively slow. On the other hand, tributaries of Green River, such as Vermilion Creek, had steep gradients into the graben and could attack and undermine the edges of the northward-dipping strata. By such rapid headward erosion Vermilion Creek succeeded in capturing a part of the northward drainage. By the same method Green River may have grown northward, capturing the major drainage of Green River basin and diverting it southward through Browns Park and Lodore Canyon. (This hypothesis is supported by the present course of Red, Sage, and Salt Wells creeks, which, as shown on figure 1, flow northward and then westward before joining Green River. Such courses suggest that these streams were originally tributaries of a river which did not flow southward to the Uinta Mountains. The absence of similar anomalies in the upper part of Vermilion Creek may be due to lateral planation during a period of temporary baselevel, when the lower part of the stream first cut down into hard rocks.) Meanders in Green and Yampa rivers that are now deeply entrenched may have developed during a period of temporary baselevel, caused, perhaps, when Green River cut through the overlying Browns Park formation and encountered the hard rocks of Split Mountain.

With the courses of the rivers once firmly established in the Browns Park beds, only time was needed to lower their channels and carve out their wonderful canyons.

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IGNEOUS ROCKS OF ITHACA, NEW YORK, AND VICINITY[1]

BY J. H. C. MARTENS[2]

(*Presented before the Society December 30, 1922*)

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INTRODUCTION

Although dikes in the region about Ithaca have been known for many years, neither extended petrographic study of them nor reliable chemical analyses have been published. In view of the unusual nature of the rock and the isolation from other igneous intrusions, a somewhat more detailed investigation of the occurrence of these dikes and their chemical and mineral composition seemed desirable. The results of this investigation are presented in greater detail in a thesis deposited in the library of Cornell University.

REVIEW OF LITERATURE

The first known record of the igneous intrusions in the small area under consideration is that by Vanuxem[35, 36] concerning the dikes at Ludlowville. The dikes at Syracuse and in East Canada Creek, near Manheim, were noted at about the same time.

[1] Manuscript received by the Secretary of the Society June 27, 1923.
[2] Introduced by A. C. Gill.

J. F. Kemp[14] recognized the rock of the Ithaca dikes as altered peridotite similar to that from Syracuse, described by G. H. Williams[40] a few years earlier. P. F. Schneider[24] recorded the size and location of several of the dikes at Ithaca and Ludlowville. G. C. Matson[21] studied the rock of the Glenwood dike, estimating in thin-sections the percentage of the constituent minerals. He also discussed the age of the dikes. V. H. Barnett[2] described the widest known dike in this region. E. M. Kindle[18] noted the size, position, and general appearance of the dikes in the southern part of our area. He included a petrographic description by Albert Johannsen.

Areal and geological Relations

The dikes of this region occur in gently folded Upper Devonian rocks, of which the Ithaca shale member of the Portage is the highest stratigraphic unit penetrated. The general south dip of the sedimentary series is reversed for a few miles by the Portland Point anticline, the axis of which crosses Cayuga Lake six miles north of Ithaca. Two prominent sets of nearly vertical joints,[25] which strike respectively within a few degrees of north-south and east-west, intersect the Devonian rocks.

All of the known dikes are found in joints of the north-south or dip set. Except at Taghanic Falls, where the dikes are tipped over to a nearly horizontal position by a small local fold, the greatest observed inclination from the vertical is 7 degrees, recorded by Kindle[18] for one of the Six Mile Creek dikes.

The location of dike outcrops on the accompanying map (figure 1) has been based partly on the Watkins Glen-Catatonk Folio and partly on observations of the writer; in one instance, also (locality number 3, in Taghanic Creek), on Matson's record. Glacial deposits and weathering products of the dikes and the inclosing rock restrict the dike exposures to rock gorges and quarries. With two exceptions, the dikes are not more than two or three feet in width. Two or more dikes with intervals of a few feet or inches between are found more frequently than single outcrops. Some of the dikes branch at the intersection of two nearly parallel joints of the dip set, but neither along the east-west joints nor following the bedding planes have offshoots been observed.

The scarcity of outcrops makes it impossible, in most cases, to determine accurately the extension of the dikes in the direction of strike. The rather frequent wedging out of dikes within the limits of the outcrop would seem to indicate that the lengths of the individual bodies at the present rock surface are small, probably seldom exceeding a few hundred or at most a few thousand feet. However, dikes, disconnected

at the surface, may extend along the same general lines of fracture for greater distances.

The dikes contain inclusions of the country rock, which are usually angular or only slightly rounded. At a few localities the inclusions are

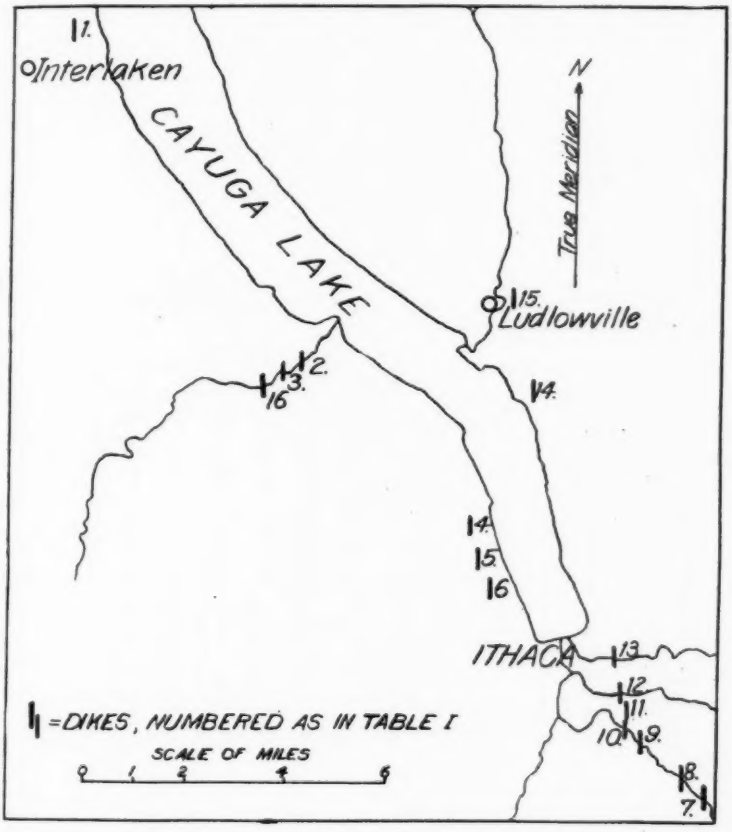

FIGURE 1.—*Location of Dikes near Ithaca, New York*

so numerous as to constitute a breccia, the fragments being shale and sandstone and the matrix the much altered igneous rock. There is no evidence of any fusion or recrystallization of the inclusions.

The contacts are usually smooth and the dikes often not attached to the wall rock. The shale and shaly sandstone are baked hard near the

TABLE I

Location, Size, and Strike of Dikes near Ithaca

Number of locality.	Earlier mention.	Location.	Number of dikes.	Width.	Strike.
1.....	.....	Lively Run, 1.3 miles northeast of Interlaken, 1,400 feet east of north-south road.	Two, 20 feet apart.	1 inch and 2 inches.	North 10° west.
2.....	Matson[21].....	At foot of Taghanic Falls.....	Four.....	Largest, 4 in.	North to south, approximate.
3.....	Matson[21].....	Taghanic Creek, "100 yards above where wagon road crosses."	One.....	2 inches.....	.....
4.....	Matson[21]..... Kindle.[15]	Glenwood Creek, one-fourth mile west of railroad.	One.....	8 feet.....	North 5° to 7° east.
5.....	Barnett[2].....	Three-fourths mile south of Glenwood, one-fourth mile west of railroad, in small ravine.	One or two..	150 feet, or 13 ft. and 25 ft.	North 15° west (west contact).
6.....	Kindle[15].....	Indian Creek, one-third mile west of railroad.	Two, 20 feet apart.	2 feet and 2 inches.	North 8° west.
7.....	Kindle[15].....	Six Mile Creek, three-fourths mile southeast of Green Tree Falls.	One.....	2½ inches.....	North 4° to 5° east.
8.....	Kindle[15].....	Six Mile Creek, 200 feet upstream from Green Tree Falls.	One.....	1¼ inches.....	North 1° west.
9.....	Matson[21].....	Six Mile Creek, one-half mile upstream from pumping station.	Two, 31 feet apart.	9 inches and 4 inches.	North to south, approximate.
10.....	Matson[21]..... Kindle.[15]	Six Mile Creek, 600 feet downstream from pumping station.	Two, 33 feet apart.	10 inches and 4 inches.	North 2° to 3° east.
11.....	Matson[21]..... Kindle.[15]	Quarry on Brandon place, southeast part of Ithaca.	Four.....	Largest, 8 in.	North 2° east.
12.....	.....	Cascadilla Gorge, Cornell University campus, Ithaca.	Six.....	.....	.....
12*a*.....	Kemp[14].....	50 feet east of Central Avenue bridge.....	.....	3 feet to 3½ feet.	North 3° east.

Number of locality.	Earlier mention.	Location.	Number of dikes.	Width.	Strike.
12*b*.....	Kindle[18].....	10 feet east of Central Avenue bridge.....	.....	3 inches.....	North to south, approximate.
12*c*.....	Schneider[24]....	140 feet west of Central Avenue bridge...	.....	2 inches to 10 inches.	North to south, approximate.
12*d*.....	Schneider[24]....	One foot east of 12*c*.....	.....	3 inches.....	North to south, approximate.
12*e*.....	Kindle[18].....	North of Eddy Street entrance to the campus.	.....	3 inches to 6 inches.	North 10° west.
12*f*.....	Kindle[18].....	2 feet east of 12*c*.....	.....	4 inches to 12 inches.	North 10° west.
13.....	Kindle[18].....	South side of Fall Creek Gorge in first deep notch east of Stewart Avenue.	One.....	4 inches.....	North to south, approximate.
14.....	Sheldon[26]..... Long.[20]	Near east side of cement rock quarry, Portland Point.	Two.....	.....	.....
14*a*.....	.....	.....	.....	0 to 18 inches..	North 9° west.
14*b*.....	.....	.....	.....	0 to 27 inches..	North 1° west.
15*a*.....	Schneider[24]....	Second ravine south of road running east from Ludlowville.	Three.....	Largest, 1½ inches.	North 6° west.
15*b*.....	Matson[21].....	Second ravine south of road running east from Ludlowville.	Seven.....	Half inch to 6 inches.	North to south, approximate.
15*c*.....	Vanuxem[26].... Schneider.[24] Matson.[21]	First ravine south of road running east from Ludlowville.	Five.....	Half inch to 6 inches.	North to south, approximate.
15*d*.....	Vanuxem[26].... Schneider.[24] Matson.[21]	First ravine south of road running east from Ludlowville.	Two.....	4 inches and 8 inches.	North 19° west.
16.....	.....	Taghanic Creek, three-fourths mile east of Halseyville.	One.....	10 inches.....	North to south, approximate.

contact with the larger dikes and show unusually close jointing. The rock within a few inches of some of the dikes contains closely spaced veinlets of calcite. No other contact minerals were observed.

Table I gives concisely the size and location of the known dikes. The locality numbers are employed to fix positions on the map (figure 1).

Petrography

The fresher rock is black to dark green and dense in appearance. Brown mica usually shows prominently, even when not present in large amount. Rarely fresh olivine of light green color is seen. More often the olivine phenocrysts are serpentinized, but are still distinguishable from the groundmass. Except for the mica, the groundmass minerals can not be recognized megascopically. With advancing alteration, the rock becomes lighter green or greenish gray and still shows the brown mica flakes.

Most of the dikes are so much altered that the original mineral composition can only be inferred from examination of thin-sections. The texture and mineralogic nature of the alteration products and the presence of considerable amounts of primary minerals in some of the dikes indicate that the rock originally contained abundant phenocrysts of olivine, and in places phenocrysts of brown mica in a fine-grained groundmass which consisted chiefly of magnesia mica, melilite, perofskite, apatite, and magnetite. All of these except the melilite are present in many specimens of the rock from several localities. Melilite was found in specimens from only two localities—Indian Creek and Glenwood—though it is believed to have been originally present in others.

The composition of the olivine is shown by the two analyses in Table II. Special attention may be called to the presence of nickel; also to the close approximation to the theoretical ratio of bivalent base to SiO_2. In number I it is 2.01 : 1 and in number II, 1.99 : 1.

Table II—*Analyses of Olivine*

	I	II
SiO_2	41.19	41.55
MgO	50.21	48.87
FeO	8.53	10.74
Fe_2O_3	0.33	n. d.
NiO	0.33	0.81
MnO	0.17	n. d.
CaO	none	none
TiO_2	0.09	n. d.
H_2O—	0.05	n. d.
H_2O	n. d.	n. d.
	100.90	101.97

I. Olivine from dike 12c, 140 feet west of Central Avenue bridge over Cascadilla Creek, Ithaca, New York. Analyst, J. H. C. Martens.
II. Olivine from dike 4, Glenwood. Analyst, J. H. C. Martens.

The minerals mentioned differ greatly in susceptibility to alteration, the melilite being the least and the mica the most resistant. The principal secondary minerals are serpentine, chlorite, and calcite. The perofskite alters to a cloudy whitish material resembling leucoxene. The dikes all contain pyrite of later introduction in small amount.

Besides the essential minerals and most common accessory minerals already mentioned, there are others present, only in very small amount, which are, nevertheless, important, as showing the constancy of certain mineral associations in widely separated regions. These minerals are chromite, picotite, graphite, red garnet, bright green diopside, and enstatite. Judging by the color, the garnet is pyrope and the diopside is of the chromiferous variety. A single flake of graphite was found in each of two dikes, imbedded in the groundmass. All of these minerals have been found in the diamond-bearing kimberlite of South Africa,[37] and therefore serve to emphasize the similarity of the two occurrences.

The Indian Creek dikes are alnoite, similar in mineral composition and texture to the alnoite dikes in the fault in East Canada Creek near Manheim,[29] New York. The Indian Creek rock contains some unaltered melilite, and the shape of the crystals is well preserved, even where the mineral is altered.

Some of the mica in the Glenwood dike is of especial interest on account of its unusual pleochroism, having greatest absorption for light vibrating at right angles to the cleavage. Such mica has been reported by P. A. Wagner[37] from South Africa and by Miser and Ross[22] from Arkansas. In both cases it was in a rock closely resembling that of the Glenwood dike.

Analyses of three of the dikes studied, together with six analyses of related rocks from other localities, are given in Table III. Of the three analyzed, the Glenwood dike is the freshest, although it has suffered considerable carbonation and hydration. The analysis of the Cascadilla dike previously made by Morrison[14] is not quoted because of its incompleteness and its large error in the determination of MgO and Al_2O_3.

With the exception of a small amount of greenish biotite, the rock chosen for analysis as representing the Ludlowville dike consists of secondary minerals. Whether the large percentage of water lost from this rock at 110 degrees was from the chlorite, which occurs abundantly in the groundmass, or from a zeolite, not observed on account of the fine grain, or was merely adsorbed by the fine powder, was not determined.

The low specific gravity of this rock is due partly to the non-removal of the air from the pores.

The two small dikes in Lively Run, near Interlaken, are so badly altered that they do not add to our knowledge of the nature of the dike rock, but they do extend the area in which these dikes are known to occur eight miles to the northwest.

TABLE III

Analyses of Alnoite, Kimberlite, and related Rocks

	I	II	III	IV	V	VI	VII	VIII	IX
SiO_2	33.38	26.37	33.20	35.25	28.83	36.80	35.49	38.84	29.81
Al_2O_3	5.09	6.14	4.45	6.10	2.94	4.16	3.42	5.88	2.01
Fe_2O_3	6.57	3.97	5.23	8.53	3.60	n. d.	6.37	7.04	5.16
FeO	4.18	4.02	3.89	5.60	5.13	8.33	3.02	5.16	4.35
MgO	23.78	16.19	28.19	20.40	24.31	25.98	30.98	22.96	32.41
CaO	9.06	16.01	6.60	7.40	11.24	8.63	5.12	9.45	8.69
Na_2O	0.44	1.46	3.38	0.70	0.75	0.17	0.20	0.33	0.11
K_2O	3.19	0.46	0.43	2.88	1.31	2.48	2.61	2.04	0.20
H_2O+	7.25	5.52	6.27	10.15*	3.96	6.93	6.69	1.50	8.92
H_2O-	0.36	5.90	1.23	.....	0.83	0.51	0.47	0.68	.....
TiO_2	2.52	1.98	1.59	2.25	5.67	1.25	1.65	3.78	2.20
P_2O_5	0.44	1.12	0.35	.....	0.77	0.47	0.63	0.89	0.35
MnO	0.17	0.19	n. d.	.....	.....	0.13	trace	0.16	0.23
CO_2	3.41	10.70	8.76	n. d.	11.64	2.95	3.03	0.43	6.66
S	0.17	0.64	n. d.	.....	.....	0.95	trace	.....	.....
Cl	0.03	0.07	n. d.	.....	.....	.....	.....	0.05	.....
Cr_2O_3	0.28	0.18	n. d.	.....	.....	.....	.....	0.18	0.43
NiO	0.10	0.09	n. d.	.....	.....	0.09	trace	0.10	0.05
BaO	0.09	.....	.....	.....	.....	0.12	.....	0.06	.....
	100.51	101.01	99.05	99.26	100.98	100.22†	99.68	100.54	100.86
Spec. gr.	2.82	2.42	.....	.....	.....	.....	2.923	.....	2.78

I. Glenwood dike, Tompkins County, New York. Analyst, J. H. C. Martens.

II. Dike near Ludlowville, Tompkins County, New York. Analyst, J. H. C. Martens.

III. Three-foot dike in Cascadilla Creek, Ithaca, New York. Analyst, J. H. C. Martens.

IV. Alnoite, Manheim, New York. Analyst, C. H. Smyth.[30]

V. Peridotite, Gates, near Masontown, Pennsylvania. Analyst, M. W. Adams.[36]

VI. Limburgite, Syracuse, New York. Analyst, H. N. Stokes.[15]

VII. Micaceous kimberlite, Lion Hill dike, Orange River Colony, South Africa. Analyst, P. A. Wagner.[37]

VIII. Mica peridotite, Crittenden County, Kentucky. Analyst, W. F. Hillebrand.[38]

IX. Peridotite, Willard, Elliot County, Kentucky. Analyst, T. M. Chatard.[3]

* Ignition loss.

† Includes .06 per cent SO_3 and trace SrO.

Composition and Relationships of the Magma

The analysis of the Glenwood dike probably gives a fairly accurate idea of the composition of the magma which formed it, although the percentages of water and carbon dioxide indicate considerable alteration. A comparison with analyses of related rocks from other localities shows a close resemblance of the Glenwood and Cascadilla dikes to rocks variously named alnoite, mica-peridotite, micaceous kimberlite, and limburgite. All of these differ from true plutonic peridotites in their porphyritic texture and in the presence of a fine-grained, usually much altered groundmass rather high in lime.

The high lime content of the groundmass of the dikes near Ithaca is shown especially by the occurrence of melilite and perofskite. No lime-bearing minerals were found as phenocrysts, except very rarely a monoclinic pyroxene which may contain some lime. The analyses show that those olivine phenocrysts remaining unaltered are free from lime, and if monticellite were ever present it is now completely altered. The abundant calcite in the groundmass and the occurrence of perofskite suggest that the groundmass of all of these dikes originally contained melilite. The oblong areas of secondary material in some of the dikes also agree with this suggestion. In the Ludlowville dikes, however, and in others which are still higher in calcite, there seems to have been an addition of calcite by water from the calcareous shales of the country rock. For the dikes of the Ithaca region it seems best to apply the name alnoite to those which contain melilite or show by their texture its former presence. The others may be called kimberlite, recognizing, however, that sharp distinctions between the two are impossible. Peridotite seems a less appropriate term for these porphyritic dike-rocks, especially since melilite, a feldspathoid, may have been originally present as an essential constituent of them all. The magma may be designated as kimberlite-alnoite.

The freshest dike-rocks of the region contain melilite, and hence are true alnoites, while others, having certain things in common with both alnoite and rocks described from South Africa as kimberlite,[37] are so much altered as to their groundmass that the original mineral composition can not be determined. P. A. Wagner[37] believes the South African kimberlites to be distinct from alnoite, although closely related. In the kimberlite of the De Beers mine, however, the only one with groundmass preserved, Wagner found a large quantity of a mineral which, from his description, is almost certainly monticellite, although not named by him, thus linking the kimberlites with the alnoite described by Bowen.[3]

Distribution of Kimberlite and Alnoite

For purposes of comparison and to show the distribution of kimberlite and alnoite, several other occurrences are of interest. In New York dikes described as porphyritic peridotite have been found at Syracuse[11, 40] and near Dewitt Center,[7, 15] three miles east of Syracuse. Melilite was found by C. H. Smyth[31] in the Green Street dikes in Syracuse and in the dikes at Clintonville,[27, 32] 15 miles southwest of Syracuse. In East Canada Creek, 100 miles northeast of Ithaca, there are some alnoite dikes which have been described by C. H. Smyth.[29]

Farther to the north are the alnoite at Saint Anne de Bellevue[1] and the monticellite alnoite at Isle Cadieux,[3, 12, 33] in Quebec. Going toward the south and west, dikes of similar composition have been described from southwestern Pennsylvania, southeastern and southwestern Kentucky,[8, 9, 10] and Riley County, Kansas.[23] All these intrusions are in gently folded Paleozoic rocks, and excepting the breccia described by Currier[6] from Hardin County, Illinois, which may represent an acid type of magma, these are the only known igneous rocks intrusive into the gently folded Paleozoic sediments in the region west of the Appalachians, southwest of the Monteregian province, in Quebec, and north and east of the nepheline syenite of Arkansas. In composition, the kimberlite of Pike County, Arkansas, belongs in the same basic group. It differs, however, from all of the others in its occurrence in rocks of Cretaceous age. In its proximity to an intrusion of the nepheline syenite magma, it is like the alnoite dikes near Montreal.

Several different names have been used for the rocks of these intrusions by the different authors who have described them, but they may be all included in the kimberlite-alnoite group. These rocks show some variation in chemical and mineralogical composition and in texture, but their similarities are much more striking than their differences.

Origin of the Magma

After referring to most of the localities just mentioned, where dikes similar to those near Ithaca are found, Prof. J. F. Kemp[17] makes the following statement in regard to their origin:

> **"Now even a small dike implies a much larger reservoir in depth. It follows that these intrusives, so closely similar in petrographic character, are in all probability the most basic and fluid differentiates of a vast and widely distributed series of magmas."**

If these are the most basic differentiates of a more acid magma, it might be expected that some of the more acid phases would occur in the

same region. However, it is more probable that they are really absent than that they are present and have escaped observation, since the outcrops would be less likely to be obscured by weathering than those of the more basic varieties. As is suggested by the quotation from Professor Kemp's address, the presence of only these basic dikes, varying little in composition at the different localities where they are found, may be due to the fact that they were the only part of a differentiated magma which was fluid enough to be forced up through a great thickness of comparatively cold rock. On the other hand, the intrusion of the more siliceous magma should be favored by its lower specific gravity, which would lessen the hydrostatic difficulties of lifting the magma many thousand feet to its present position.

These dike rocks are mentioned by H. S. Washington[39] in his discussion of comagmatic regions. He says:

> "These appear to be surficial extensions of a general body of magma which underlies the greater part of this area."

P. A. Wagner,[37] in attempting to explain the origin of the South African kimberlite, considered it highly probable that the whole region in which these rocks occur in South Africa is underlain by a universal zone of peridotite, which was differentiated enough to furnish the different varieties of kimberlite. The wide distribution of this type of material seems to force the acceptance of one of two conclusions: either that an extensive reservoir furnished the dike bodies or a local condition of frequent recurrence was responsible. These explanations are not mutually exclusive, however. The explanation by local conditions might be most simply furnished by invoking, as has been done, the reaction of limestone to form a melilite bearing syntectic. The writer is inclined to the view that a wide area underlain by material of a composition similar to that of kimberlite and alnoite furnishes the best explanation of the source of the magma which formed the dikes near Ithaca and the related small intrusions which have been mentioned. Such a hypothesis was suggested by Jillson[13] in a recently published paper.

The occurrence of only such basic igneous rock at these several localities over such a large area suggests that similar heavy material may be present in large amount much nearer to the earth's surface than is ordinarily supposed; perhaps even close enough to cause a serious error in such an estimate of the composition of the earth's crust for a depth of 10 miles as was made by F. W. Clarke.[5] Such a possibility is further borne out by Washington's[38] estimate of 50.06 to 50.63 per cent of silica in the rocks of the oceanic basins, three-fourths of the earth's surface,

as compared with 59.77 per cent for the whole ten-mile shell of the lithosphere.

The alnoites in Quebec are near intrusions of a great variety of less basic alkaline rocks, and the igneous rocks nearest to the kimberlite of Pike County, Arkansas, are the nephelite syenites of the Magnet Cove and Potash Sulphur Springs regions, which are probably of the same age as the kimberlite.[42] It is, therefore, possible that the kimberlite-alnoite magma is a basic differentiate of a more siliceous alkaline magma, such as would form nepheline syenite or essexite. On the other hand, the hypothesis seems worthy of consideration that the nepheline syenite is a "leucocratic" differentiate of a very large mass of kimberlite-alnoite magma which is so heavy that only small portions of it have ever been pushed far enough to be exposed by erosion.

Conditions and Method of Intrusion

There is little evidence as to the thickness of sedimentary rock which has been eroded from above the dikes near Ithaca. It may have been very little or it may have been a few thousand feet. The sharp contacts and the lack of contact metamorphism indicate a low temperature of the country rock at the time of the intrusion. The north-south joints must have been formed and there must have been little or no east-west pressure to keep them shut. The large amount of angular inclusions in the smaller dikes may be taken as evidence that no great quantity of magma moved up through these fissures; therefore, that they may very well not have reached the surface.

The magma evidently had a very low viscosity, as otherwise it could not have formed such thin dikes as some of those found. The basicity of the magma as well as a possible content of water and other mineralizers would tend to explain its fluidity. The possibility that the magma took up enough salt from the three hundred feet of salt beds through which it passed to notably increase its fluidity does not receive confirmation from the trace of chlorine now observable. Of course, leaching may have removed most of it, if it was ever present.

Age of the Dikes

The writer has not found any new evidence as to the age of the dikes near Ithaca; so the conclusions of other authors will be briefly summarized.

G. C. Matson[21] came to the conclusion, based on structural evidence, that the dikes near Ithaca were probably intruded during the period of

Appalachian folding near the close of the Paleozoic. From the relation of the joints to the dikes and to the folds, E. M. Kindle[18] regards the "late Devonian or Carboniferous age as probable but not demonstrated."

From the occurrence of one of the alnoite dikes in East Canada Creek in a fault fissure, of which the simplest explanation is that it was formed at the time of the Appalachian uplift, C. H. Smyth, Jr.,[20] concludes that these dikes were intruded near the close of the Carboniferous, and that the Ithaca and Syracuse dikes are probably of the same age.

From the fact that the dike in Fayette County, Pennsylvania, coked the coal of the Pittsburgh seam, Prof. J. F. Kemp[17] favors the lapse of a long period of time between the deposition of the Monongahela formation and the intrusion of the dike into it, to allow the formation of a coking bituminous coal. The known Cretaceous age of the Pike County, Arkansas,[22] kimberlite supports Kemp's argument, although this locality is so far distant from the others under consideration that like petrographic character is not conclusive evidence of like age.

It is probable that dikes similar to those near Ithaca are exposed in central and western New York, others than those which are known, since the dike outcrops are inconspicuous and would easily escape observation. The fact that two new exposures have been reported in the fall of 1923 supports this view. There seems, therefore, to be hope that further discoveries may be made which will throw additional light on the problems of the origin of the magma which formed these dikes and the time and manner of its intrusion.

Summary

This study of the frequently mentioned dikes of the Ithaca region has led to—

I. Mapping all known localities.

II. Confirmation of occurrence only in the north-south joint planes.

III. Analysis of three of the dikes.

IV. Designation of the magma as kimberlite-alnoite, on account of the presence, as also in South Africa, of both melilite-bearing rocks and of similar rocks in which melilite is not recognizable.

V. Finding of garnet, chromite, picotite, graphite, and diopside, as in South Africa.

VI. Consideration of the bearing of these occurrences on some of the broader questions of the nature and origin of rock magmas.

VII. Résumé of opinions on the age of these and related rocks.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PENNSYLVANIAN CORRELATION IN NORTHWESTERN ILLINOIS[1]

BY HAROLD E. CULVER

(*Read before the Society December 28, 1923*)

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INTRODUCTION

The area under consideration lies in northwestern Illinois and includes about 500 square miles in Bureau, Henry, Rock Island, and Mercer counties.

This study was initiated in 1921, by the State Geological Survey of Illinois, as a result of the discovery, in the cap rock of the Rock Island, or No. 1 (Pottsville), coal, of a Fusulina which has been considered an index fossil for the basal bed of the McLeansboro formation, the Upper Pennsylvanian of the Illinois field. Two queries immediately presented themselves for consideration:

(1) Is the Fusulina, *Girtyina ventricosa,* a reliable index for the McLeansboro formation?

[1] Manuscript received by the Secretary of the Society January 18, 1924.
Published by permission of Chief, Illinois State Geological Survey.
Introduced by E. S. Bastin.

(2) Are the upper strata in the Rock Island area of Pottsville or McLeansboro age?

Inspection of the problem suggested the need of a rigid scrutiny of all evidence for correlation within the Pennsylvanian in this area. Studies were undertaken which it was hoped would serve to determine the actual relations between the beds classed as Pottsville and those classed as McLeansboro.

Essential stratigraphic Facts of the Area

Devonian limestones and shales outcrop along the northwest margin of the area and are known generally from drilling elsewhere. Lying unconformably on these are the beds of Pennsylvanian age which underlie the surficial materials throughout the region.

The Pennsylvanian beds range in thickness from a few feet near the Devonian area to a known maximum of more than 200 feet. These in-

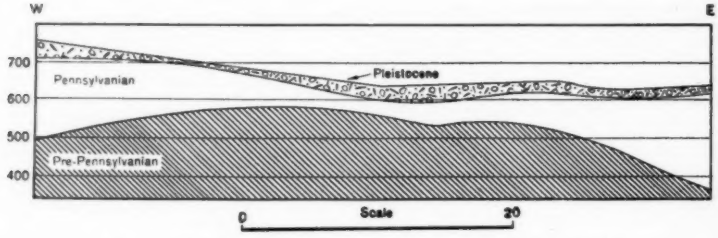
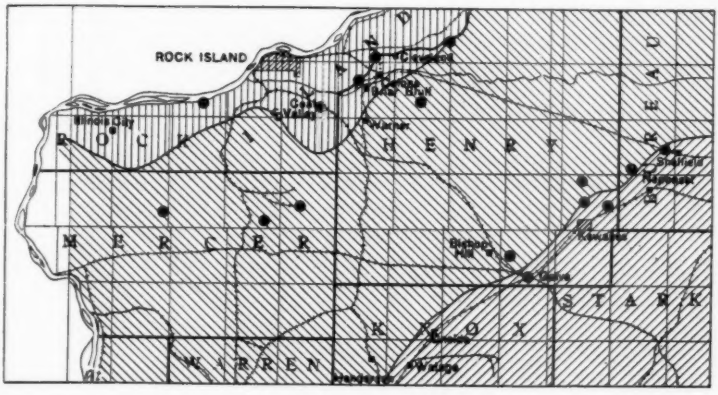


Figure 1.—*Diagrammatic Section across northwestern Illinois*

clude some shaly clastics, one or two thin limestones, and a few mainly discontinuous beds of coal. The general character of these beds indicates their deposition in a zone marginal to the sea, most of the strata probably being of fresh or brackish water origin. With certain important exceptions, these beds are lenticular, showing lithologic variation vertically as well as laterally in short distances.

They are essentially flat lying, although locally the relief is nearly 50 feet to the mile. The meager data at hand indicate a somewhat uneven pre-Pennsylvanian surface. While insufficient to permit the drawing of contours, they still show a definite high area in eastern Rock Island County, with the area east and west at lower altitude. Because of this major elevated portion, the thickness of the Pennsylvanian varies accordingly, and a diagrammatic structure section across the area is presented to give the general relations of surficial, Pennsylvanian, and older deposits.

In the early reports on the Pennsylvanian series in Illinois no specific subdivision of the whole was attempted. There was worked out by Worthen and his associates, however, a sequence of some sixteen coal beds and associated strata. The coals were numbered from the base of the Pennsylvanian upward and State-wide correlation attempted. Later work by De Wolf and others has been the basis for a tripartition, giving


ROCK ISLAND
Geneseo
Galva
Kewanee
Wyoming
Princeton
Peru
Ottawa
Streator
Marseilles
Morris
Joliet
Wilmington
Braidwood
Dwight
Pontiac
Watseka
Kankakee
Momence
Chicago Heights
Hammond
Gary
Valparaiso
Michigan City
Elkhart
Goshen
Plymouth
Rochester
Logansport
Kokomo
Peru
Wabash
Huntington
Fort Wayne
Warsaw
Auburn
Angola
Hillsdale
Coldwater
Sturgis
Kendallville
Albion
Coldwater
Bronson
Coldwater
Sturgis
Kendallville
Albion
Bronson
Hillsdale

top of coal No. 6, the limestone overlying this coal belonging at the base of the McLeansboro formation. In the Worthen text no such distinction is made between this coal and its cap limestone. Consequently, the area here mapped as McLeansboro includes the top bed of the Carbondale. An error less than the refinements of the mapping is thus introduced, which is all the less important in view of the fact that the coal actually does not extend appreciably west of the limit of its protecting cap limestone.

Applying these formation names to the data presented in the Worthen report, we find the McLeansboro extends from the central part of the Illinois coal basin northwestward as far as the mines near Galva. The boundary passes in a nearly northeast-southwest direction through Galva, including Sheffield on the northeast and Wataga on the southwest. To the northwest lie older beds, of which the Pottsville, the lower formation, underlies the northern part of Rock Island County and extends eastward along Rock River in northwest Henry County. The remaining middle and southern portion of this northwestern district is underlain by beds classed as Carbondale.

Basis of earlier Correlation

GENERAL STATEMENT

Before considering any new line of stratigraphic evidence, it is well to scrutinize that which has been used for earlier correlation, and so far as possible to evaluate it, so that due weight may be given to the several groups of data. Pennsylvanian correlation in northwestern Illinois has been based on some apparently outstanding characters, which suggested an identity with certain strata elsewhere in the State, rather than on detailed study within the area. Three lines of evidence have been followed—lithologic, floral, and faunal.

LITHOLOGY

Although apparently satisfactorily correlated with the general Illinois section, the strata in the northwestern area did not receive the careful study which marked the investigation of other parts of the State by the Worthen Survey. As a result, we find Rock Island, or No. 1, coal[2] so classed because of its general characters, unspecified, and its peculiar limestone cap with an accompanying band of flint. No. 2 coal is identified primarily by the presence of a bed of septaria below the coal. No. 2 and No. 6 coals are each recognized by a shale parting. The use of such means of recognition of these beds is obviously open to question.

[2] A. H. Worthen: Geol. Survey of Illinois, vol. v, 1873, p. 198.

FLORA

The next important contribution was made by David White,[3] who based his correlation on fossil plants. These studies, much more thorough than anything previously attempted, were still of reconnaissance character, admittedly hasty, but yet productive of results highly suggestive, if not final. Of especial significance are the opinions expressed by White, (1) that Pennsylvanian deposition in southern Illinois was distinctly earlier than in the Rock Island region, and (2) that striking incompatibilities attended the designation of the various coals then known as "No. 1."

It is not the intention of the writer to suggest any change from the inferences made by White, but rather to point out that the data were insufficient for final conclusions. Because of lack of study of specimens from different zones in the McLeansboro or upper Pennsylvanian, the data presented by White are inadequate for the problem at hand. Specifically, the plants associated with the Rock Island coal, which he considered to be distinctly younger than the Pottsville of southern Illinois and older than the McLeansboro of Danville, may still be early McLeansboro rather than late Pottsville.

In the past decade attention has not been centered on correlation problems, and by repetition the tentative conclusions published by White have gained more weight than originally was claimed for them. The guarded expressions in which they are phrased show that he felt the time and material available to have been insufficient for final decisions. It seems to the writer, therefore, that until detailed examination of really extensive collections of plant fossils has been made, we can not look to paleobotany for decisive correlation.

FAUNA

Following the early statements by Worthen, there grew up in the literature of Illinois geology a conception, rarely seriously challenged, that most of the species composing the faunas of the Pottsville range throughout all Pennsylvanian beds. It seems unreasonable to affirm that in the wide expanse of the Eastern Interior basin during the whole of Pennsylvanian time there was no opportunity for the development of distinctive faunas at several horizons. The writer firmly believes that a critical study of extensive collections will reveal such index faunas and possibly index species. Furthermore, if, as suggested by another line of evidence, the basal Pennsylvanian near Rock Island is really McLeansboro, the basis for the conception of extreme vertical range of species is rendered questionable.

[3] David White: Report of the field work in the coal districts of the State. Illinois State Geol. Survey Bull. 4, 1907, p. 201.

Among those few species which have been regarded as having a limited vertical range is one of the foraminifera known as *Fusulina cylindrica* var. *ventricosa,* or as *Girtyina ventricosa.* This shell, uniformly present in the limestone cap of No. 6 coal, came to be regarded as one of the few reliable index fossils. As recently as 1921 Savage[4] placed the upper beds of the Rock Island area in the McLeansboro formation on the basis of Fusulina.

In the past two years, careful search in outcrops, mines, and drill cores has revealed the presence of fusulinas in unexpected abundance. Not only have fusulinas been found at one horizon in the Pottsville, two in the Carbondale, and at least three in the McLeansboro; but two or three apparently different types have been found in the cap of No. 6 coal alone. From these occurrences it appears probable that other types have been mistaken for *Girtyina ventricosa,* and that until detailed study of these forms has been made the correlations based on them can not fairly be regarded as conclusive.

Basis of present Correlation

Lithologic sequence

The unsatisfactory nature of available data emphasized the need for a more reliable basis for correlation. Recognition of the lenticular form and lateral variations which characterize Pennsylvanian deposits in this field led to an attempt to determine a lithologic sequence of moderate vertical extent which might be traced throughout the area.

It was assumed that such a sequence would represent a definite series of events in the depositional history which would not have been duplicated frequently, if at all. If such a sequence can be satisfactorily traced from the area of recognized McLeansboro into the area of Pottsville beds, it demonstrates either a continuity of identical strata or an unexpected repetition of depositional conditions in all three subdivisions of Pennsylvanian time.

Details of section

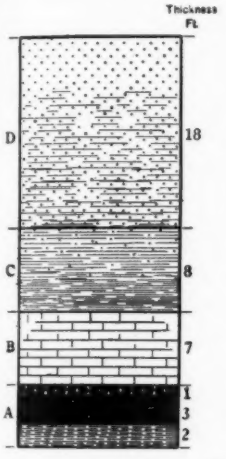
A recognizable sequence was found in the strata associated with the main coal of the region. The coal, with its underclay, forms the base of the section, which comprises the beds shown in the accompanying diagram.

For inspection and comparison, consider the section to comprise a carbonaceous zone (A) at base, followed by three zones, which are respectively (B) dominantly limy, (C) clayey, and (D) sandy. An im-

[4] T. E. Savage and J. A. Udden: Geology and mineral resources of the Edgington and Milan quadrangles. Illinois State Geol. Survey Bull. 38, 1921, p. 149.

portant feature is the lack of stratigraphic break, marine deposition apparently having followed that of carbonaceous matter almost immediately. It is probably unnecessary to state that each of the four zones shows recognizable characters which are difficult to describe. This section, essentially as described, occurs at places which are well distributed across the area from east to west, as shown in figure 2.

Throughout this distance the beds lie at or near the top of the Pennsylvanian section, except in parts of Mercer County, where some 80 feet of strata lie above them. Their relation to the pre-Pennsylvanian rocks



DESCRIPTION OF STRATA

D — 18 — Sandstone, shale partings, light colored, thin beds, grades down.

C — 8 — Shale, sandy, light colored above; non-gritty and darker below, grades down.

B — 7 — Limestone, highly argillaceous except at base, locally sandy, dark gray, abundant marine fossils.

1 — Slaty shale.

A — 3 — Coal, with shale above and clay below.

2 — Clay.

FIGURE 3.—*Section from Pennsylvanian in northwestern Illinois*

is less uniform. At the east, there is an interval of some 200 feet between the base of the section and the pre-Pennsylvanian surface. In the north-central part this is reduced to less than 40 feet, while farther south and west the interval is again greater.

In places, later Pennsylvanian beds replace part or all of the four zones, and apparently locally, as at Annawan, post-Pennsylvanian erosion gave rise to valleys exposing beds 150 feet below the No. 6 coal. Rather generally over the area, however, part or all of this group of beds may be recognized.

VARIATIONS AND THEIR INTERPRETATIONS

Although, as stated, the four zones composing this section can be recognized practically throughout the area, there is some variation in lithologic character of the several beds which merits attention. For ex-

ample, the calcareous zone traced westward from Sheffield is increasingly argillaceous. This increase in clastic material is commonly accompanied by increased amounts of carbonaceous matter, giving the rock a darker color. With these changes in composition a change in fossil content is observable. The cleaner limestone has many corals, bryozoans, brachiopods, and fusulinas, which in the more clayey parts are less abundant and of smaller size, gastropods and pelecypods predominating. Throughout the region, however, the basal part of the calcareous zone is the least argillaceous and carries most of the fossils. In the vicinity of Briar Bluff, where the Devonian lies about 30 feet below the carbonaceous zone, there is marked local variation in the limy zone. Here the basal limestone is distinctly lenticular, a relatively clean twenty-inch bed becoming argillaceous and pinching out in about 50 feet. These and all other observed variations in the character of the limestone zone appear to be gradual, so that the correlation from point to point offers no great difficulty. The larger features of the variations point to this area as the margin of the calcareous deposition, and since this is roughly coincident with the area of thin Pennsylvanian beds, a causal relation is suggested.

Variations in the clayey and sandy zones are less marked, but yet are especially well defined in the area of greatest change in the underlying bed. The prominent feature is the introduction of coarser material in the elsewhere fine-textured clastics.

These changes in character, it should be emphasized, are reversed when the beds are traced from the Briar Bluff region southwestward into the area where the Pennsylvanian system is thicker.

Conclusions

The foregoing presentation of data seems to the writer to warrant the following conclusions:

1. The early correlations by the Worthen Survey were based on unreliable criteria.

2. The paleobotanical correlations can not be considered final until based on much more extensive collections.

3. In view of the duration of Pennsylvanian time, it seems unreasonable to assume that there was no development of distinctive faunas at several horizons. Miscorrelation may account for the prevalent conception. More careful comparison of fusulinas is needed before correlation on that basis can be regarded as conclusive.

4. The apparent continuity throughout this area of a definite lithologic sequence constitutes an important line of evidence which favors the conception of an extension of the Upper Pennsylvanian west of the limit heretofore recognized.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PILLOW STRUCTURE IN THE TRIASSIC BASALTS OF CONNECTICUT[1]

BY WILBUR G. FOYE

(*Presented before the Society December 29, 1923*)

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THE THREE RANGES OF PERCIVAL

Percival[2] was the first geologist to recognize that the trap ridges of the central part of the Connecticut Valley were divisible into three groups. The higher ridges, with a steep cliff to the west and a gentle slope to the east, he called the Main ranges. At the foot of the steep western slopes there are usually subordinate shelves, which he called the Anterior ranges. On the gentle back slopes toward the east are other

[1] Manuscript received by the Secretary of the Society December 29, 1923.

[2] James Gates Percival: Report on the geology of the State of Connecticut. New Haven, 1842, p. 324.

subordinate ridges, which he called the Posterior ranges. Later investigations have shown that the terms have a chronological as well as a spatial significance. The Anterior ranges are now known to be lava-flows erupted before the eruption of the flows forming the Main ranges, and the Posterior ranges represent lava-flows poured forth at a considerable interval of time after the Main sheets were erupted.

Character of the Main and posterior Ranges

Within the borders of Connecticut the Main and Posterior ranges show much similarity. They are composed of basaltic flows probably poured forth from fissures in the earth's crust in a very fluid condition. There is scanty evidence of a succession of flows, even in the Main sheet, which is 500 feet in thickness. Two flows may be recognized at Lane's quarry, north of Meriden, but even here the interval between must have been slight. The flows crystallized with little evidence of explosive violence and are quite coarse-grained, almost gabbroid, near their centers. Vesicular structure is common near the upper and lower surfaces, but is rarely found within the main body of the sheets.

The Anterior Range

GENERAL STATEMENT

In contrast with the Main and Posterior ranges, the Anterior range is formed of a number of interbedded lava-flows and explosive agglomerates. Davis[3] emphasized the existence of the agglomerates to prove the extrusive character of the igneous rocks composing the Anterior range. It is the purpose of this paper to describe the several types of igneous structures associated with the Anterior range, and to inquire as to their significance with respect to the Anterior range itself and also with respect to the history of the Triassic trough of Connecticut.

TYPICAL EXPOSURES

Typical exposures of the rocks forming the Anterior range may be found just west of Lamentation Mountain, three and one-half miles northeast of Meriden (figure 1, locality 4). The narrow band just east of the figure 4 represents the Anterior range. At no place is the complete series of rocks forming the range exposed. At a locality widely known as "Davis's ash bed," situated at about the midpoint of this portion of the range, sandy shales lie at the bottom of the exposure and at the southern end of the outcrop a considerable thickness of the red sand-

[3] W. M. Davis: The Triassic formation of Connecticut. 18th Ann. Rept. U. S. Geol. Survey, 1897, vol. 2, pp. 62-67.

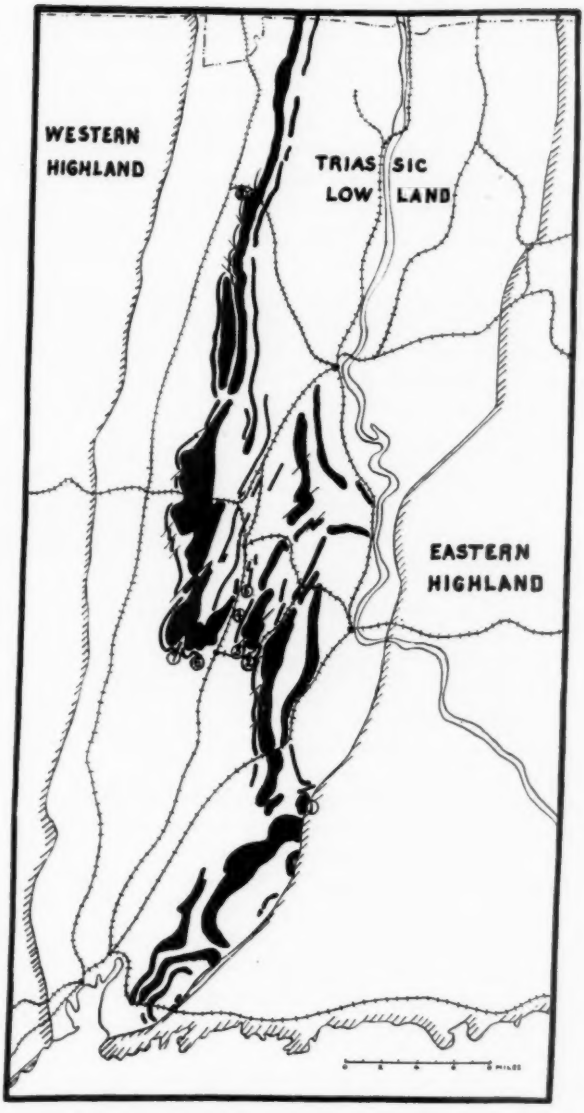

FIGURE 1.—*Sketch Map of the Triassic Lowland of Connecticut*

stone of the valley type was exposed just below a layer of agglomerate. A drilled well at this point met sandstone one foot beneath the surface and was drilled through it to a depth of 75 feet. The average dip of the beds is 20 degrees east-southeast.

Overlying the sandstone and usually forming the basal member of the Anterior series is a low ledge of agglomerate, 25 to 30 feet in thickness. It is composed of fragments of vesicular basalt and indurated red sandstone up to 8 or 10 inches in diameter. The ledge is frequently hidden by the talus from the overlying basalt, but again it appears to be lacking and the basalt rests on the sandstones beneath.

Above the agglomerate is a flow of basalt, 100 to 125 feet in thickness. The top of the flow is coarsely vesicular through a thickness of 5 to 6 feet. The vesicles are often an inch or more in diameter and the fractured character of the surface of the flow would indicate that it was composed of a typical Aa lava. Below the vesicular upper portion the sheet

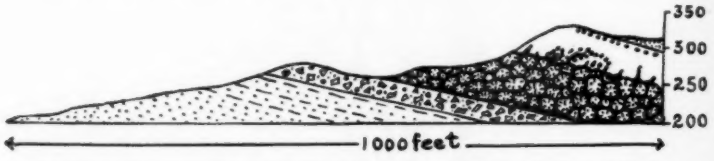

FIGURE 2.—*Generalized Cross-section of Anterior Range in Vicinity of Meriden*

is fairly dense through a thickness of 10 to 15 feet, and then very frequently pillow structure makes its appearance. The pillow structure extends, in every case where it is exposed, to the base of the outcrop; whether it extends to the bottom of the sheet is not known, but it is believed that it does. Roughly, a third to a half of the exposures of basalt along the Anterior range of Lamentation Mountain shows pillow structure. The sketch (figure 2) shows a generalized cross-section of the range in the vicinity of Meriden.

At the northern end of the Anterior range of Lamentation Mountain, at a locality frequently referred to as "Emerson's mud volcano," there are agglomerate layers, interbedded with shale and sandstone to a thickness of 12 to 15 feet, overlying the basalt. In general, basalt flows interbedded with agglomerate come and go along the strike, indicating that they were irregular tongues of no great thickness or length at the time of their extrusion.

DAVIS'S ASH BED

A well known locality situated near the center of the Anterior range of Lamentation Mountain has frequently been referred to as "Davis's

ash bed." The locality was first discovered by Prof. W. M. Davis and several students, during a geological excursion, in the Easter recess of 1887. It was described by him in a paper on "The intrusive and extrusive Triassic trap sheets of the Connecticut Valley."[4] Some years later Professor Emerson reviewed the geology of the same locality.[5] The outstanding features are rounded blocks of basalt, sometimes dense throughout, but again hollow at their centers or very vesicular, set in a greenish gray paste which Davis referred to as "ash." In his earlier papers Professor Davis considered the blocks of basalt to be volcanic "bombs" from some near-by vent, but later[6] he acquiesced in Emerson's

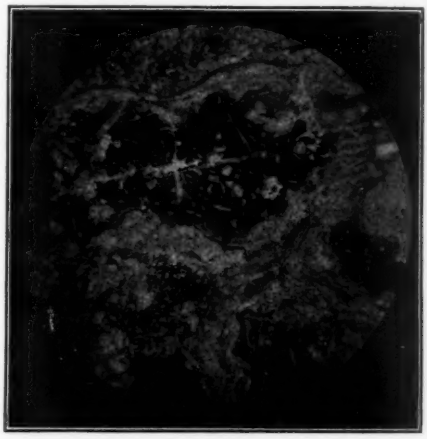

FIGURE 3.—*Microphotograph of the altered Glass at Davis's Ash Bed*

interpretation of the locality. Like structures are now known to be exposed in the Anterior of Chauncey Peak (locality 3, figure 1).

Professor Emerson believed that as the lava-flow advanced it overflowed a body of water, which was transformed into steam, and as a result "the basal bed of the compact trap" was "carried up into the glass above by explosion, sometimes as broad sheets, sometimes as rounded and remelted blocks with peripheral steam-holes." The brecciation and hydration of the glass, making it appear like "ash," he attributed to the same cause.

Figure 3 is a microphotograph of the brecciated material at the "ash

[4] Bull. Mus. Comp. Zool., vol. 16, 1889, pp. 118-120.
[5] B. K. Emerson: Bull. Geol. Soc. Am., vol. 8, 1897, p. 66.
[6] 18th Ann. Rept., U. S. Geol. Survey, vol. 2, 1897, p. 65.

bed." It is composed of altered glass fragments containing laths of plagioclase feldspar and spherulites of chlorite. Surrounding the fragments is a paste of highly altered glass composed of calcite and chlorite and frequently scapolite. Evidently hydrothermal alteration went on at a very high temperature. The "ash" grades upward into a finely vesicular basalt of the pahoehoe type, which is also highly altered, and thin-sections show the presence of scapolite as well as the other secondary minerals referred to above. Many of the "bombs," which are frequently one to two feet in diameter, have a red outer shell similar to that described by Doctor Diller[7] as present on lava from El Pinar, San

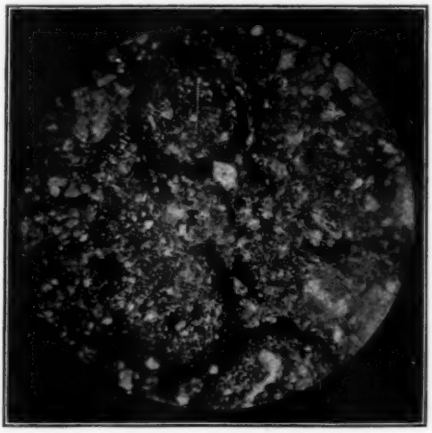

FIGURE 4.—*Microphotograph of the pisolitic Shale at Emerson's locality*

Salvador. The writer believes such surfaces are only produced on lavas exposed to the atmosphere when at a high temperature. He raises the question whether these blocks of basalt may not have been true "bombs." Professor Davis rejected his first theory because the nearest vent he knew of was 10 or 11 miles away, at Mount Carmel; but the writer believes that vents may be found nearer the eastern fault border of the valley. They may be concealed by the later trap flows and sediments of the upper series of the Triassic; at least one such vent is exposed within 100 yards of the border at Durham (locality 1, figure 1). May not the presence of the scapolite indicate that hydrothermal alteration was carried on by volcanic exhalations issuing from a near-by vent?

[7] Bull. Geol. Soc. Am., vol. 33, 1922, p. 142.

EMERSON'S MUD VOLCANO

Near the northern end of the Anterior range of Lamentation Mountain is another well known locality, referred to frequently as "Emerson's mud volcano" (locality 5, figure 1). Professor Emerson[8] described the locality in the same paper in which he discussed "Davis's ash bed." Again he inferred that the mass of agglomerate occurring at this locality had been formed by the explosion of steam beneath flowing lava. Although this explanation may account for part of the agglomerate, it certainly can not account for it all. Almost within the mouth of the

FIGURE 5.—*Pisolitic Shale interbedded with Agglomerate*
(Emerson's locality 5, figure 1)

vent through which the steam is supposed to have exploded, there are six or seven layers of agglomerate, varying in thickness from 6 inches to 2 feet, which are separated by layers of a pisolitic sandy shale 2 to 10 inches in thickness.

A study of the rounded globules of the pisolitic layers (figures 4 and 5) shows that they are not concretionary, but are composed of small angular fragments of quartz, feldspar, and mica, with some basaltic fragments, surrounded by a film of clay or limonite containing small bits of mica. The material forming the pellets is, therefore, largely derived from the sandstones and ultimately from the crystalline rocks

[8] Bull. Geol. Soc. Am., vol. 8, 1897, pp. 67-68

of the Eastern Highland. The pellets greatly resemble mud balls rained down during the eruption of Mont Pelée in 1902 and also during the eruption of Taal Volcano in 1911,[9] but an exact comparison can not be made, since the material is not, to any considerable degree, of volcanic origin. It is fine and angular and is, therefore, believed to be of wind-blown origin, carried by winds excited by the heat of a central vent. The writer believes the pellets were formed by raindrops which fell into fine, loose dust. The process may be compared to that employed by W. A. Bentley, of Nashville, Vermont, in the measurement of raindrops. A thin layer of fine uncompacted flour is exposed during a rainstorm and the dough pellets formed are found to have the approximate diameter of the raindrops falling during the exposure.

FIGURE 6.—*Pillow Structure at Tariffville*

Whatever the exact method of the formation of the pisolitic layers, they appear to indicate that the Meriden region at the time of their formation was a barren waste, either because of the vulcanism characteristic of the Connecticut Valley at that period or because of the aridity of the region, and show that the agglomerates at Emerson's locality could not result from a single steam explosion.

PILLOW STRUCTURE

Localities.—It has been stated that pillow structure is frequently found in the lava-flows forming a part of the Anterior range of Lamentation Mountain. Not only is it found here, but in the Anterior of Cathole Mountain (locality 6, figure 1), the Anterior of East Peak, just below

[9] Wallace E. Pratt: "An unusual form of volcanic ejecta." Jour. of Geol., vol. 24, 1916, p. 450.

the Pavilion (locality 7, figure 1), and the Anterior of Talcott Mountain below Bartlett tower, Tariffville (locality 8, figure 1; see figure 6). It is, therefore, frequently found within the lavas of the Anterior range of Connecticut. On the other hand, it is not known to occur in the lavas of the Main or Posterior ranges.

Associated with Aa flows.—The surfaces of the flows showing the development of pillow structure, wherever exposed, are distinctly of the Aa type. They contain vesicles one-half of an inch to one inch in diameter, are well crystallized, and are broken by cracks which are now filled with secondary minerals, such as quartz and calcite (compare figure 8).

Position of development.—The pillow structure of the Anterior flows is by no means a surface phenomenon. As stated above, it begins to make its appearance 15 to 20 feet below the top of the flows and beneath a considerable thickness of dense lava. The glass surrounding the pillows very evidently developed along cracks which shot through the lava while it was still in a viscous state, and these cracks die out upward into the adjacent dense lava (compare figures 8 and 10). There is no surface of discontinuity between the lava showing the pillow structure and the overlying basalt; hence there is no evidence that later flows of a different character covered the sheets showing pillow structure. The field evidence is conclusively in favor of the view that the pillow structure developed in lava flows which had come to rest before the structure was formed.

Description of the structure.—The pillows vary from a foot to 3 or 4 feet in diameter and are usually surrounded by layers of basaltic glass, now greatly decomposed, 1 to 3 inches in thickness. The centers of the pillows are quite dense, but pipestem vesicles radiate near their edges toward the glassy outer shell. Often the vesicles branch as they approach the surface of the pillows. No vesicles have been discovered which quite reach the glassy shell, but they die out in the very fine-textured layer lying just beneath that shell. The paths of the gases forming the vesicles were so regular that it is very apparent that the viscous material through which the gas migrated could not have been disturbed during the formation of the vesicles. The drawing (figure 7) illustrates the way in which the vesicles are frequently arranged. Pillow A is separated from pillow B by a crack along which there is no glass, but, as shown, the glass between pillows A and C penetrates for a distance into this crack. The crack containing no glass evidently was situated in a zone of reduced pressure, since vesicles X and Y, by their direction, indicate a reduction of pressure not only where the glass was formed, but between pillows A and B as well. The hammer in figure 8 rests in a cavity from which basaltic

glass has weathered away. Following to the left, along the direction in which the hammer head is pointing, are cracks which die out into dense trap. Near the glass pipestem vesicles radiate toward the cracks, but farther to the left the vesicles get smaller and smaller and finally disappear. In the central, upper border of the picture is a pillow showing radiating vesicles, but without a glassy cover.

In the tetrahedral openings between the pillows, crystals of calcite and quartz are frequently found, but the zeolites so well known in the New Jersey examples of pillow structure do not occur. At least, they have

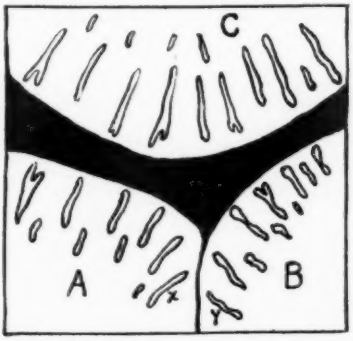

FIGURE 7.—*Pipe-stem Vesicles radiating from Center of Pillows toward glassy Edges*

not been discovered up to the present time. Figure 9 shows the structure of the altered glass lying between the pillows. The minerals present are similar to those occurring in the "ash" at "Davis's ash bed," but angular fragments of altered glass are more common.

The basalt forming the center of the pillows has a fine, ophitic texture and is composed of labradorite and augite in about equal proportions. Phenocrysts of clinoenstatite are frequent and secondary minerals, such as serpentine and calcite, are present.

ORIGIN OF THE PILLOW STRUCTURE

No evidence of subaqueous origin.—A. K. Wells, in a recent paper on "The problems of the spilites" [10] has made the statement, that "in view of the evidence brought forward by Lewis, one would be bold to deny the possibility of something akin to pillow structure being found in subaerial flows, but the geological record contains few, if any, definitely known examples of such." The physiographic conditions which existed in the

[10] Geol. Mag., vol. 60, 1923, p. 65.

Connecticut Valley during the deposition of the rocks forming the Anterior range do not support the hypothesis that the Connecticut examples of pillow structure are subaqueous in origin. Evidence has already been presented to show that the region was a barren waste, either because of the explosive vulcanism of the period or because of the aridity of the

FIGURE 8.—*Pipe-stem Vesicles radiating toward joint Cracks along which no Glass developed*

climate. The evidence presented by Barrell[11] has been generally accepted, showing that the Connecticut Valley was a semiarid region, similar to the Great Valley of central California, during the greater portion of the period covered by the Triassic deposition. Exceptionally playa

[11] Joseph Barrell: Central Connecticut in the Geologic Past. Bull. 23, Connecticut State Geological and Natural History Survey, p. 30.

lakes may have dotted its surface; but it is difficult to believe that enough water was present to submerge the lava-flows of the Anterior range wherever pillow structure is found. If the region about Meriden alone is considered, pillow structure occurs persistently in the Anterior basalt flows over an area stretching from Lamentation Mountain (locality 4, figure 1) to the Hanging Hills (locality 7, figure 1) in an east-west direction, and from Chauncey Peak (locality 3, figure 1) to Tariffville (locality 8, figure 1) in a north-south direction.

Fenner[12] has suggested that lava-flows overran shallow bodies of water which were converted into steam, and the "jets and tongues of fused

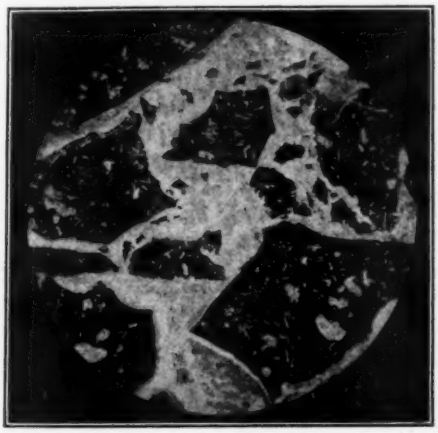

FIGURE 9.—*Microphotograph of the Structure of altered Glass*

Lying between the pillows at the quarry on the old turnpike—locality 5, figure 1.

material seem to have assumed the consistency of a thick syrup, and instead of spreading laterally they solidified in smoothly rounded, boulder-like masses having considerable similarity to the 'pahoehoe' of Hawaiian flows." Steam arising from shallow bodies of water or from the underground water-table beneath a lava-flow may have influenced the development of pillow structure, but that is very different from the conception implied by the term "subaqueous."

Misconceptions concerning pahoehoe flows.—The above quotation from Fenner suggests a brief discussion of the "bulbous budding" hypothesis

[12] Clarence N. Fenner: The Watchung basalt and the paragenesis of its zeolites and other secondary minerals. Ann. N. Y. Acad. Sci., vol. 20, 1910, p. 100.

of J. V. Lewis.[13] In both the statements of Fenner and those of Lewis the pillow structure results from the surface of a lava-flow coming into direct contact with air or water, and thereby forming an outer coating of glass which is later rounded into a pillow. Each separate pillow represents, therefore, the advanced edge of a lava stream. The "bulbous budding" of a pahoehoe flow, such as Lewis illustrates by plate 23, figure 1, of his article, is distinctly a *surface* phenomenon. It has been stated above that the pillow structure of the Anterior range of Connecticut is

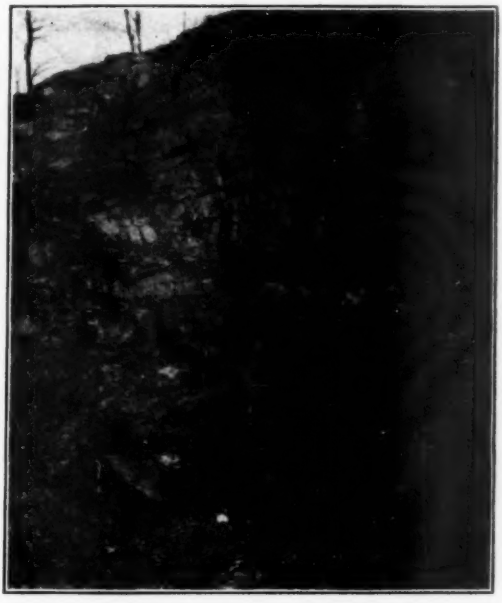

FIGURE 10.—*Domes rising into massive Basalt*
From pillow basalt beneath—locality 5, figure 1.

clearly *not a surface* phenomenon, but is found near the center of the sheets.

Again, the pillows were developed *after* the sheet ceased to flow and not as a result of its advance. The evidence which the writer believes supports this view may be summarized as follows:

(1) The glass has formed along zones of tension separating the pillows; it dies out in an irregular manner along joint cracks which pene-

[13] Origin of pillow lavas. Bull. Geol. Soc. Am., vol. 25, 1914, p. 646.

trate into the dense lava above the pillow structure (compare figure 8), or the pillows degenerate into a coarsely vesicular lava which rises in a dome into the overlying dense trap. Two such domes are shown in figure 10. Pillow structure may be seen in the foreground, but disappears just beneath the feet of the man standing near the top of the quarry. The man is pointing to one of the domes, and a second is shown to the left of the photograph at the same level.

(2) There is no surface of discontinuity separating the dense lava above from that showing the pillow structure below; hence there is no evidence that a second flow covered a pahoehoe surface. Quite to the

FIGURE 11.—*Pillow Structure at the Quarry on the old Turnpike*
(Locality 5, figure 1)

contrary, the field evidence shows clearly that the dense structure and the pillow structure developed in a continuous body of lava.

(3) Most of the pillows are spherical and are not flattened by the weight of the overlying pillows, as one might expect if a bulb of viscous glass with a fluid interior were subjected to a load after being formed in the front of a moving lava stream. (Compare figures 6 and 11).

(4) The gas moving outward from the interior of the pillows through the viscous basalt migrated along regular paths which were radial to the centers of the pillows. If the pillows were being tumbled over one another by an advancing lava flow, an interior which was fluid enough to

allow the formation of pipestem vesicles 4 or 5 inches long must have been disturbed by such violent movements.

(5) The field occurrence does not in the least resemble the "bulbous" surface of a pahoehoe flow.

Factors influencing the development of pillow structure in the Anterior sheets.—The outstanding fact concerning the lavas showing pillow structure in Connecticut is that they are confined to the Anterior range. The chemical and mineralogical character of the lavas forming the Main and Posterior ranges are entirely similar to those of the Anterior range. Other factors must, then, be sought to explain the formation of the structure. As far as is known, the physiographic conditions within the valley were similar during the extrusion of the lavas forming the three ranges. The chief difference lies in the fact that the Anterior range was formed by explosive eruptions, whereas the Main and Posterior ranges were probably the result of quiet extrusion of very fluid lavas from fissures.

Explosive vulcanism is usually considered to be due to three factors:

(1) The lavas filling the vent may be so viscous that they clog the vent and can only be forced out by the explosion of the gases rising beneath them.

(2) The lavas filling the vent may be deficient in heat. They, therefore, quickly freeze over and the plug can not be removed until a sufficient supply of heat and gases has accumulated to violently disrupt the obstruction.

(3) The presence of excess gases in lavas may lead to explosive vulcanism.

The Anterior lavas are entirely similar to those forming the Main and Posterior sheets; hence there is nothing inherent in their composition which would lead to explosive vulcanism because of abnormal viscosity. The Anterior lavas were unable to flow as far, however, as the Main and Posterior lavas, since they form discontinuous sheets of no great lateral extent. It is not believed, therefore, that they had much, if any, superheat at the time of their extrusion, as did the other sheets. The abundance of vesicles in the Anterior lavas shows that they were filled with occluded gases at the time of their extrusion. Low temperature and occluded gases are believed to have been the main factors, therefore, which produced the explosive vulcanism characteristic of the Anterior sheet.

What have these factors to do with pillow structure? H. S. Washington has shown that these factors—that is, low temperature and high

gas content—are characteristic of the Aa type of lava-flows. Quoting from a recent article, he says:

"Under these conditions of great fluidity and lower temperature, the crystallization of labradorite and augite begins early and proceeds with rapidity. The fluidity of the liquid portion and the consequent rapidity of the crystallization are maintained and, indeed, enhanced. In the first place, the separation of the crystals, in which the gases are not appreciably soluble, increases the gas concentration (and the pressure) within the remaining liquid, thus maintaining a high degree of fluidity. . . .

"Two other factors also tend to preserve fluidity. . . . The one is connected with what has been called the 'second boiling point'—that is, the increased gas pressure resulting from the formation of crystals in a cooling liquid. The formation of crystals in a liquid lava gives out latent heat, . . . so that crystallization itself will tend to maintain the temperature of the still fluid portion, or diminish the slope of the cooling gradient.

"The other possible factor is . . . that feldspar begins to crystallize first, augite and magnetite belonging to the later stages of crystallization. . . . Because of this early crystallization of the feldspars, the portion of the lava that remains liquid becomes increasingly femic and therefore more and more fluid. . . .

"The liberation of gas from the mass of Aa will thus be increasingly rapid, possibly violent toward the end, and the crystallization of the lava which forms Aa is consequently very rapid after a certain degree of fluidity has been reached, the great fluidity of the steadily diminishing liquid portion of the flow being maintained up to the point of complete solidification." [14]

The solidification curve of Aa lava, according to Washington, would be somewhat as shown in figure 12.

Is it not possible that an Aa lava, cooling under the conditions postulated by Washington, might become undercooled? Should the explosion of steam derived from the water in a porous mass of agglomerate beneath the flow, or should any other cause, aided by the tensions set up, due to the cooling and crystallization of lava, tend to disrupt the viscous basalt from below, the gases, which alone keep the lava in a fluid condition, would be released and rapid cooling along the tension zones, shooting upward from the base of the flow, would produce glass along any joint cracks formed in the viscous mass. Toward these zones of reduced pressure the occluded gases within the viscous lava would tend to migrate. May not the irregular domes of vesicular lava lying above the pillows have been produced by clouds of gas rising into the lava from below and released in the process of the formation of the pillows? (Compare figure 10.)

[14] Am. Jour. Sci., vol. 6, 1923, pp. 421-422.

Relation of explosive Vulcanism to the Triassic Faulting

In a recent paper[15] the writer has outlined his reasons for believing that the Triassic trough of Connecticut was produced by the tilting of a monoclinal block which was bounded by a single fault along the eastern border. In this trough the Triassic sandstones and shales were deposited. The fault began to develop in middle or later Triassic time and movements continued along the zone up to the end of the Triassic deposition. Is it not reasonable to suppose that the volcanic forces within the centro-

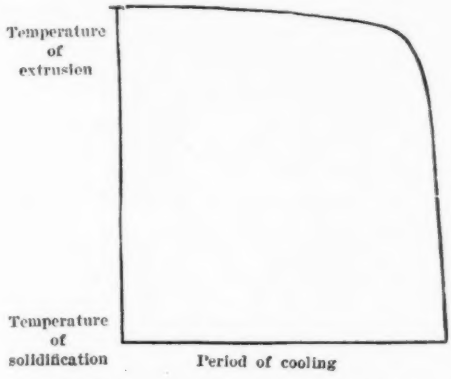

FIGURE 12.—*Cooling Curve of an Aa Lava*

sphere first began to discover the zone of weakness along the Triassic basin of Connecticut at the period of the eruption of the lavas forming the Anterior sheet? A large part of the heat supply of the ascending magma would have been consumed in the initial attempt to make its way to the surface; but at the same time the gases within the magma chamber tended to collect in large amounts within the cupola of the chamber, and thus the initial vulcanism of the valley was marked by explosive violence and by the extrusion of lavas relatively low in temperature but high in gas content. Once the magma chamber had been tapped and the channels of extrusion were developed, the later extrusions found it easier to rise to the surface without loss of heat, and their gases were less abundant because of easier avenues of escape.

The writer would, therefore, consider the explosive character of the rocks forming the Anterior range as added evidence to show that block

[15] Origin of the Triassic trough of Connecticut. Jour. of Geol., vol. 30, 1922, p. 690.

faulting was going on *pari passu* with the deposition of the sandstones of the Connecticut Valley. The faulting which broke the extrusive sheets represents a second period of faulting at the end of Triassic or in early Jurassic time.

ACKNOWLEDGMENTS

The writer is glad to acknowledge his indebtedness to Prof. W. N. Rice and Doctor Adolph Knopf, with whom he discussed many of the facts presented in this paper.

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LAMINATED ANHYDRITE IN TEXAS[1]

BY JOHAN AUGUST UDDEN

(*Presented before the Society December 28, 1923*)

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INTRODUCTION

Recently Mr. David Flood has made a diamond drill exploration on the Gresham and McAlpine farm, located on section 42, block 54, State school lands, in Culberson County, Texas. The location is some twenty-two miles west-northwest of Toyah. The test has lately been completed. It extends to the depth of 3,705 feet. A study of the cores enables us to correlate the formations penetrated with formations previously known only from exposures.

GEOLOGICAL SECTION EXPLORED

THE SECTION

The section of the strata explored can be tabulated briefly as follows:

[1] Manuscript received by the Secretary of the Society December 26, 1923.

	Depth in feet.	
	From.	To.
The Rustler Formation, 205 feet:		
(1) Brecciated yellowish gray dolomite	0	205
The Castile Formation, 1,905 feet:		
(2) Broken up mixture of gypsum and some red sands	205	238
(3) Brecciated gypsum and anhydrite	238	784
(4) Gray impure sand	784	820
(5) Anhydrite, partly changed to gypsum and having indistinct laminations	820	840
(6) Gray sand with gypsum veins, in part broken up	840	850
(7) Somewhat coarsely laminated anhydrite, slightly disturbed	850	875
(8) Laminated anhydrite	875	924
(9) Shale	924	927
(10) Laminated anhydrite	927	950
(11) Shale and anhydrite	950	976
(12) Laminated anhydrite	976	979
(13) Shaly brecciated anhydrite	979	986
(14) Laminated anhydrite, practically one uninterrupted bed, except for a little shale at 2,064 feet	986	2,150
The Word Formation, 1,298 feet:		
(15) Black shale and fine-grained sandstone	2,150	2,900
(16) Dark limestone, in part sandy	2,900	2,965
(17) Dark shale and fine-grained sandstone	2,965	3,075
(18) Dark limestone	3,075	3,171
(19) Mostly sands of fine texture, with some shale	3,171	3,448
Age not known, 257 feet:		
(20) Sandstone of fine texture, with alternations of some dark and some brown shale	3,448	3,705

RUSTLER FORMATION

From an examination of the surrounding country, it is evident that number 1 in the above section is the formation which has been described as the Rustler formation by Richardson. It is seen in the Rustler Hills and is almost everywhere affected by fracturing and irregular dislocations, which may be characterized as brecciation on a large scale. The rock is a fine-grained dolomite.

CASTILE GYPSUM

It is also evident that number 3 in the above section is a part of the Castile gypsum, also described and named by Richardson. Numbers 2, 4, 6, and 9 are arenaceous and argillaceous strata, which have not previously been described in the Castile gypsum, probably on account of not

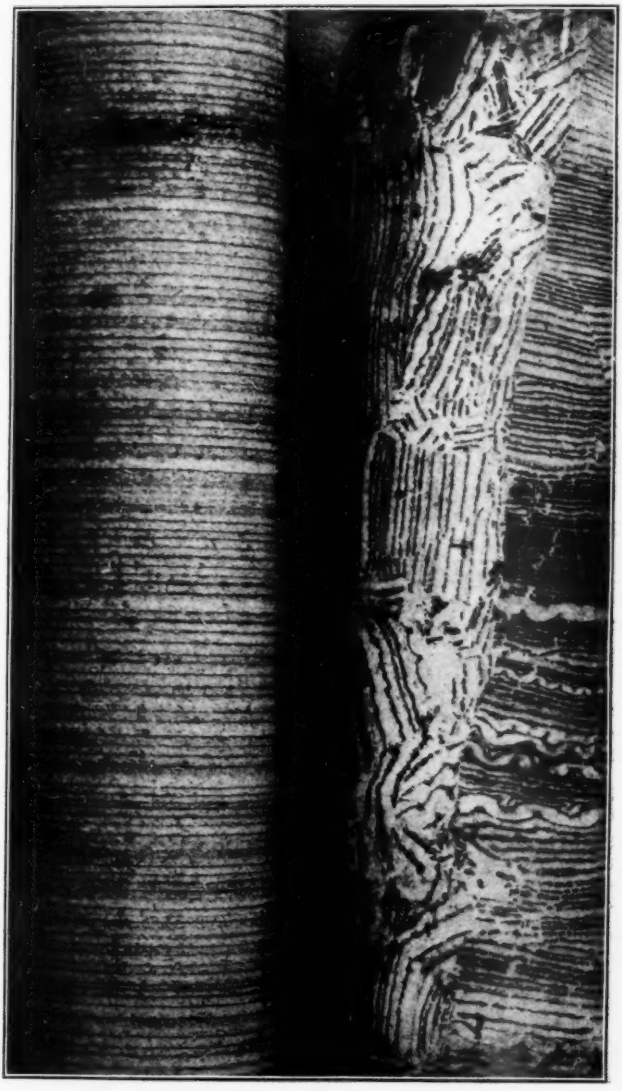

FIGURE 1.—TYPICAL LAMINATED ANHYDRITE

Natural size of core. Depth, 2,118 feet.

FIGURE 2.—BRECCIATED ANHYDRITE OCCURRING IN A FAULT

Natural size. Depth, 1,195 feet.

LAMINATED AND BRECCIATED ANHYDRITE

FIGURE 1.—ANHYDRITE PARTLY CHANGED TO GYPSUM

Developing crystals of selenite. Slightly reduced. Depth, 368 feet.

FIGURE 2.—BRECCIATED GYPSUM AND SHALE

Slightly reduced. Depth, 420 feet.

FIGURE 3.—BRECCIATED GYPSUM AND SHALE

Slightly reduced. Depth, 525 feet.

FIGURE 4.—INCIPIENTLY BRECCIATED GYPSUM WITH SOME SHALE

Hydration incomplete and laminations still visible. Slightly reduced. Depth, 872 feet.

being exposed. We see in these some interruptions in the otherwise continuous deposition of calcium sulphate extending through 1,945 feet of the section, from 205 feet below the surface down to 2,150 feet. From 825 to 986 feet we have some alternations from gypsum to sand, shale, and anhydrite. The gypsum here contains some anhydrite, and the anhydrite contains some gypsum. These strata are in the process of change from anhydrite to gypsum. In the anhydrite as well as in the gypsum in this interval, laminations of the original rock are visible at many places in the core. The layers have swelled, as it were. When anhydrite changes to gypsum, its volume increases by as much as from 30 to 60 per cent. From 986 feet down to 2,150 feet is practically a single continuous bed of anhydrite, very regularly laminated and quite unaltered. This part of the core should, no doubt, be referred also to the Castile gypsum. It was evidently deposited in the same basin as the Castile gypsum without any considerable interruption.

WORD FORMATION

From 2,150 feet below the surface down to 3,705 feet, the beds penetrated consist of fine sands alternating with black shales and some dark limestone. This part of the core has several horizons carrying a cephalopod fauna characteristic of the Word formation in the Glass Mountains. This fauna is here associated with various other organic forms, such as scales and teeth of fish, some crustaceans and radiolaria, the latter being confined to the upper few hundred feet of the formation. The Word formation is a part of the Delaware formation. In the Glass Mountains the Word formation, in its greatest development, has a thickness of nearly 1,500 feet. In this boring it was penetrated for a depth of some 1,200 feet, or for 1,555 feet if the lowest part of the section be regarded as also belonging to the Word.

Structure of the Region

In the judgment of the present writer, the section from 205 feet to 2,150 feet below the surface represents, as already stated, the Castile formation. In this region, the formation dips to the east or southeast at a rate of 80 feet per mile. The underlying Word formation comes to the surface farther to the west. The zone of radiolarians, in the upper part of the Word, has been identified from cuttings 40 miles east from this boring, at a depth of about 4,300 feet.

From a number of observations made in different parts of the State, it is well established that gypsum beds in the Permian change to anhy-

drite at a distance below the surface varying from 400 to 700 feet. There is, therefore, no doubt in the mind of the present writer that the brecciated gypsum, shown in the core, was originally deposited as anhydrite and has since taken up water and become gypsum. Evidence of such a progressive change is found in the brecciation of the Rustler dolomite and of the gypsum beds themselves. The boring passed through 606 feet of gypsum and under this, 1,262 feet of anhydrite. The original thickness of the 606 feet of gypsum could not have been less than some 380 feet. The total thickness of the anhydrite as originally laid down can, therefore, be estimated to have been, in round numbers, 1,640 feet. This figure is on the basis of allowing for 60 per cent of increase of bulk in the gypsum. With the impurities present in the gypsum, perhaps 1,600 feet would be a more nearly correct figure. For oil geologists it may be interesting to note that should the hydration have gone on at uneven rates in different places, decided structures might show in the overlying Rustler Hills limestone without affecting the oil-bearing strata below the gypsum.

Lamination in the Anhydrite

The layers in the anhydrite average less than two millimeters in thickness and their extreme variations lie between two-tenths and seventy-tenths millimeters. The most common variations are between five-tenths and twenty-tenths millimeters. The demarcations of the layers are made by very thin layers in which occur microscopic thin films of a brownish material from which a small amount of bitumen or oil may be distilled. These layers are darker than the more pure anhydrite which forms the bulk of the core. Together with this bituminous material, there are also microscopic crystals of calcite. This bituminous material and the calcite, in most cases, measure less than one-fourth of the thickness of each lamination. It is evident that each layer composed of these two elements represents a cycle of precipitation and sedimentation in the water in which the anhydrite was laid down. It is certainly a most remarkable record of sedimentation, whatever be the length of the cycles recorded, that such uniform conditions should have prevailed during a time in which 1,262 feet of anhydrite or more likely 1,640 feet of the same kind of sediments had time to accumulate. Although the core examined shows some irregularities due to small crumpling and faulting, there is no reason to believe, from the appearance of the whole, that during this time there was any disturbance in the bottom of the water where the sediments were deposited, nor any considerable interruptions in the process.

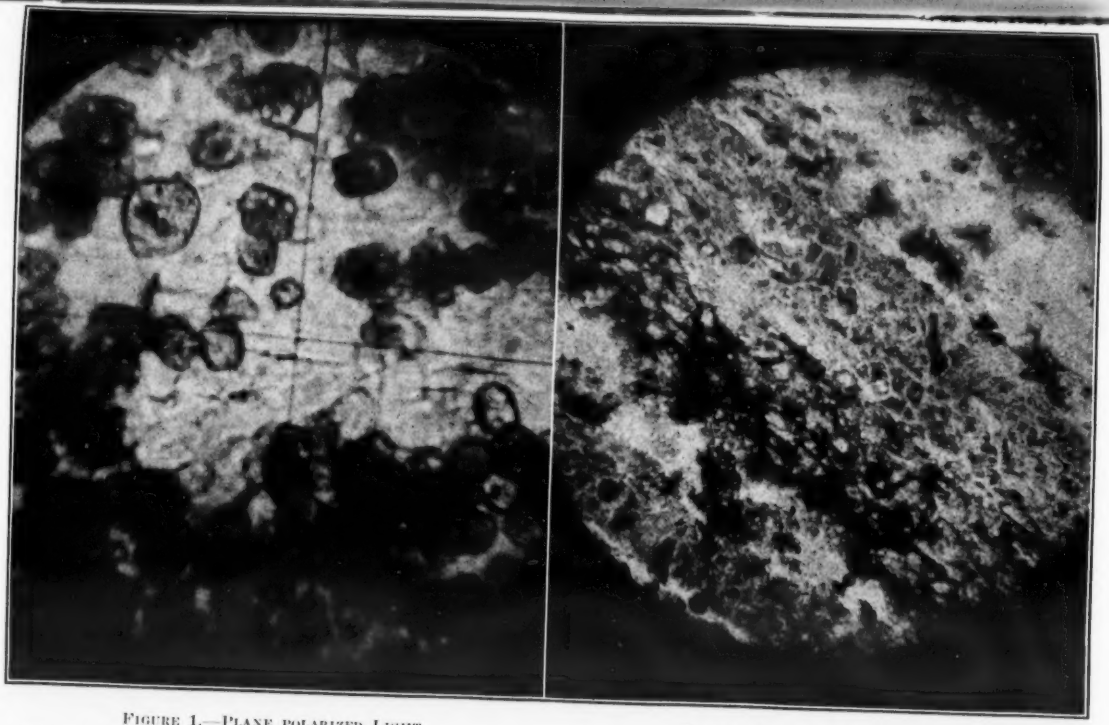

FIGURE 1.—PLANE POLARIZED LIGHT

High magnification (350 ×) showing shape of primary calcite or dolomite crystals. Depth, 2,023 feet.

Some crystals having this shape whose highest index of refraction is above 1.67 have been found in some of these cores. Photograph and notes by T. L. Bailey.

FIGURE 2.—PLANE POLARIZED LIGHT

This photograph shows a thick layer of calcite running diagonally across the center, with a thick anhydrite layer above it and a thin layer of anhydrite below it. The central calcite layer is composed mainly of elongated to columnar calcite crystals with irregular areas of light anhydrite filling the spaces between crystals. The lower part of this lamina is heavily stained with bitumen. Small patches of finely crystalline calcite occur scattered through anhydrite laminae. Depth, 2,148 feet. 71 ×. Photograph and notes by T. L. Bailey.

MICROPHOTOGRAPHS OF CALCITE

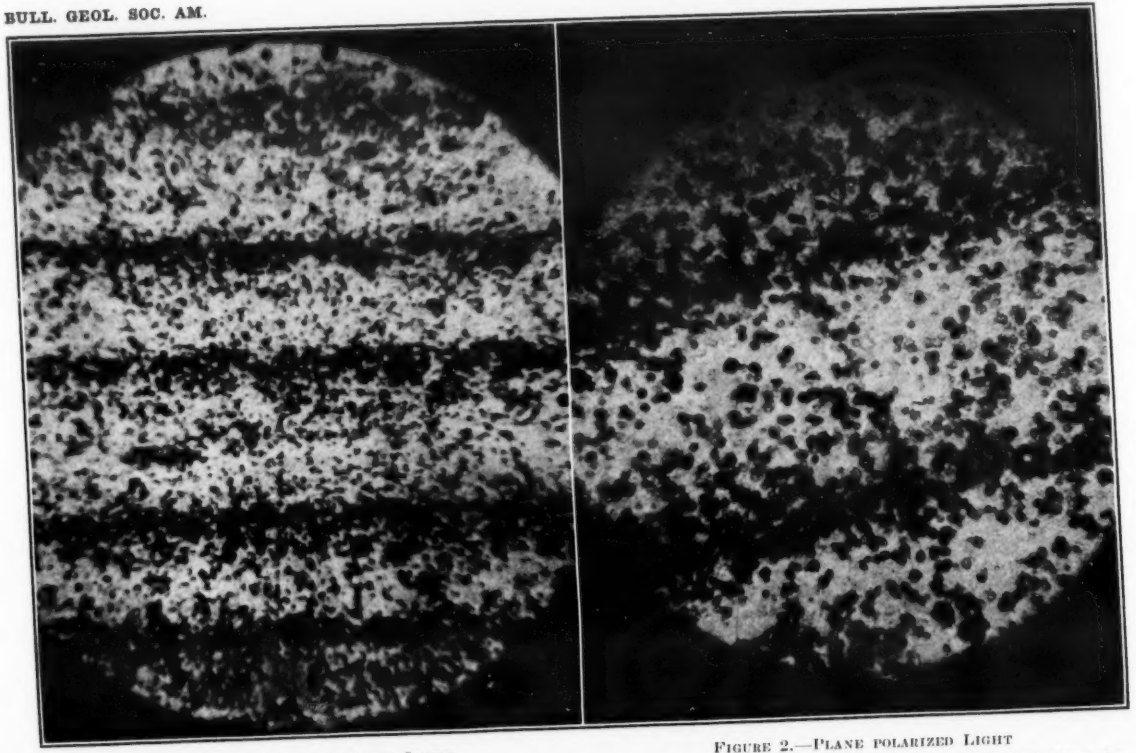

FIGURE 1.—PLANE POLARIZED LIGHT

Dolomite or calcite is in dark laminæ. It is all composed of small rounded rhombs of nearly like diameters. These rhombs are also scattered through the anhydrite, but are concentrated in the dark laminæ. Depth, 2,023 feet. 30 ×. Photograph and notes by T. L. Bailey.

FIGURE 2.—PLANE POLARIZED LIGHT

Two dark laminæ are composed mainly of rounded rhombohedrons of calcite or dolomite of a uniform size. The lighter portions of the photograph are made of anhydrite. Dolomite or calcite crystals are scattered through the anhydrite layers, too, but are greatly concentrated in the two dark layers. One faint cubic crystal of fluorite is noted about the center of the photograph. Depth, 2,023 feet. 71 ×. Photograph and notes by

Cycles indicated

For most of the core the average thickness of the laminations is about the same, as will be seen from the accompanying table; but in all parts of the core there are variations and, as a rule, the thickest occur in successive groups. This is suggestive of cycles. It is not yet known whether the laminations represent days or years, or other cycles of intermediate duration; nor can it yet be said that they may not be due to periodic variations, wholly independent of weather conditions or climatic conditions.

The greatest number of layers measured in one continuous succession of core was 1,737. This part of the core extended from 1,809 feet to 1,822 feet below the surface. Averaging these measurements in groups of thirty layers, it is seen that at intervals of from eleven to fourteen of these groups there is a fairly regular recurrence of one maximum and one minimum. In the maxima the layers average about twice as thick as in the minima. It should be stated that it is not always possible to distinguish every separate layer. Probably 2 per cent of the layers are indistinct. It is impossible to determine whether in every case a layer should be regarded as a single double layer or as two separate layers. Taking this into consideration, it would not seem to be entirely impossible, so far as the maxima and minima here referred to are concerned, that they may represent annual cycles. In the case of another core taken at 1,949–1,952 feet, there is a gradual change, so that a series of 180 successive layers average about 2 millimeters, and these are followed by another series of about 180 layers that average 1.7 millimeters. In the case of still another core, extending from 1,954–1,957 feet, there is a gradual increase and decrease in the thickness through 340 layers, and another cycle is suggested, but apparently incomplete, in 250 laminations, that are continuous with the first cycle.

Other cycles are indicated for much shorter periods. The number of laminations in each of these smaller cycles vary from five to nineteen, but there is an excess of cycles that comprise six or seven and twelve or thirteen laminations. There are also many cycles that measure eight, nine, and sixteen layers. In one short part of the core there are pronounced periodic recurrences of much bituminous material near every seventh and every thirteenth layer. The frequency of the numbers twelve and thirteen suggests sun-spot cycles.

The periodic variations in thickness of the layers may be due to several cycles of unequal length. That each layer should represent the sediment of a single day seems hardly probable. If the precipitation of the ma-

terial in each layer were due to daily evaporation, this evaporation would be in great excess over any known conditions in the present seas. If, on the other hand, a single layer should represent the accumulation during a year, the quantity of water evaporated would seem small. But I believe that this would be nearer to our common-sense estimate of the amount of materials that might accumulate annually in a basin of water where calcium sulphate has reached the point of saturation, and where water thus saturated is constantly supplied, as under the conditions postulated by the so-called bar hypothesis.

Other Problems involved

Everything considered, there are a great many circumstances to consider in finding the true explanation of the laminations in this anhydrite. The presence of other salts in the same waters must have had an important bearing on the quantity of anhydrite that was precipitated. The presence of organisms which contributed the bituminous material may also have had its influence. This might tend to accentuate the demarcation of any cycles.

The question also presents itself whether the water in which the deposition occurred was open or whether it may have been ice-bound. And if it were ice-bound, would the cooling incident to the water flowing in under a covering of ice have any influence on the precipitation? To what extent might such cooling enter as a factor in the amount of the material precipitated, and is it conceivable that a microfauna or a microflora might exist and show periodic increased activities corresponding to climatic cycles under such conditions? The great regularity of the laminations persisting through such a long duration of time, as is indicated by the thickness of the deposit, and showing no effects of disturbances of any kind on the bottom of the sea, suggest unusually quiet conditions, such as can hardly be supposed to exist in an open sea. The influence of surface waves might effect a mingling of successively settling layers with each other, and thus make the resulting deposit a continuous and homogeneous rather than a laminated deposit.

Conclusion and Table of Measurements

In the following table I have shown the results of some preliminary measurements that have been made on parts of the core from different depths below the surface. Together the measured cores have a length of 1,098 centimeters (36 feet). In these parts of the core there are 6,436 layers. This gives an average thickness of each layer of about 1.63

millimeters. If the layers represent the annual cycles, it is readily seen that the length of time during which all this precipitation took place was approximately three hundred and six thousand years. This figure is somewhat commensurate with the estimated duration of some of our glacial periods in the Quaternary.

Table showing the average Thickness of some Layers in the Anhydrite from 1,122 to 2,143 Feet below the Surface in the Gresham and McAlpine Ranch Test in Culberson County, Texas

The averages for each hundred feet are based on one or several cores of stated lengths and depths.

Depth of cores in feet below surface.	Length of cores in centimeters.	Number of layers in each core.	Average thickness of layers in each core, in millimeters.	Estimated average thickness of layers for each 100 feet in the hole, in millimeters.
1,122	20.3	108	1.87	1.87
1,258	20.4	110	1.85	1.85
1,307	43.6	206	2.11	....
1,363	22.4	167	1.34	....
1,394	26.7	190	1.40	1.61
1,449	19.0	70	2.71	2.71
1,530	17.7	218	.81	.81
1,620	21.0	184	1.14	....
1,623	28.5	195	1.46	....
1,626	7.5	70	1.07	....
1,679	24.0	113	2.12	1.44
1,734	17.4	103	1.69	1.69
1,809	345.5	1,737	1.98	....
1,850	19.5	167	1.16	1.57
1,945	95.2	480	1.98	....
1,953	41.2	197	2.09	....
1,954	116.0	591	1.96	....
1,970	26.0	296	.87	1.72
2,023	9.0	72	1.25	....
2,027	18.0	125	1.44	....
2,093	16.5	156	1.05	....
2,097	13.0	122	1.06	1.20
2,111	15.0	102	1.47	....
2,114	20.5	120	1.70	....
2,117	13.0	90	1.44	....
2,118	41.5	234	1.77	....
2,131	18.0	182	.98	....
2,143	21.7	131	1.65	1.50
Totals.....	1,098.1	6,436		

Average thickness of measured layers..... 1.63

All measurements in the foregoing table were made by Miss Dorothy Noyes Shoaf.

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PRE-CAMBRIAN ROCKS OF THE WESTERN PIEDMONT OF MARYLAND[1]

BY ANNA I. JONAS

(*Presented before the Society December 28, 1923*)

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INTRODUCTION

The Piedmont of Maryland occupies a belt about 55 miles wide, extending across the central part of the State from the Pennsylvania-Maryland line to the Potomac River. Its southeastern edge is the "Fall line," marked by such towns and cities as Elkton, Havre de Grace, Baltimore, Laurel, and Washington, and its northwestern boundary is Catoctin Mountain. The Piedmont is for the most part a rolling upland underlain by pre-Cambrian crystalline rocks, and it comprises, in the western

[1] Manuscript received by the Secretary of the Society February 2, 1924.
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part, the Frederick Valley, underlain by Paleozoic rocks, and the Triassic lowland which lies along the eastern edge of Catoctin Mountain.

The area of the pre-Cambrian rocks of the Piedmont of Maryland is divided for geologic reasons into an eastern and a western belt by the Peach Bottom syncline, which crosses the Pennsylvania-Maryland line at its intersection with the Susquehanna River, north of Conowingo. This syncline extends southwest from Cardiff through Greystone, Baltimore County, to Sykesville, Carroll County, whence it curves southward to the Potomac River near Washington. The eastern belt, lying southeast of the Peach Bottom syncline, is widest in Baltimore County, but to the south, in Howard and Montgomery counties, it extends under Coastal Plain sediments east of Laurel and Washington.

General Geology of the eastern Piedmont of Maryland

The stratigraphy of the eastern Maryland Piedmont[2] has been worked out in detail by E. B. Knopf and the writer in a recent survey of Baltimore County. The studies on which this paper is based were carried on in Carroll County and a part of Frederick County, in pursuance of the detailed survey of the Maryland Piedmont begun in 1919 for the Maryland Geological Survey.

The pre-Cambrian rocks exposed in the eastern and western Piedmont of Maryland are as follows:

		Western Piedmont	Eastern Piedmont
Pre-Cambrian	Glenarm series		Post-Glenarm intrusives
		Peters Creek schist	Peters Creek schist
		Wissahickon albite-chlorite schist facies	Wissahickon oligoclase-mica schist facies
		Cockeysville marble and interbedded volcanic rocks and tuff	Cockeysville marble
			Setters formation
			Unconformity
			Hartley augen gneiss (intrusive)
			Baltimore gneiss

The oldest rock of the eastern belt is the pre-Cambrian Baltimore gneiss, a light-colored, thoroughly recrystallized rock of sedimentary

[2] E. B. Knopf and A. I. Jonas: Stratigraphy of the crystalline schists of Pennsylvania and Maryland. Am. Jour. Sci., vol. 5, January, 1923.

origin, which in some places is a heavily bedded gneiss of granite aspect, while in other places it is a thinly banded ribbon gneiss. The dominant constituents are quartz, oligoclase, microcline, and biotite. It has been intruded by a granite, the Hartley augen-gneiss, which has produced a lit-par-lit injection in the upper part of the formation.

The Glenarm series, 8,000 to 10,000 feet thick, unconformably overlies the Baltimore gneiss. The series comprises, in ascending order, Setters quartzite, Cockeysville marble, Wissahickon formation, and Peters Creek schist. The lower formations of the Glenarm series are cut by large intrusions of plutonic rocks, granites, diorite, and gabbro, as well as by pyroxenites and peridotites.

The Wissahickon formation throughout the Maryland and Pennsylvania Piedmont develops two contemporaneous facies, the one called the oligoclase-mica schist facies, which was metamorphosed under deep-seated conditions; the other, the albite-chlorite schist, which is the result of recrystallization in the uppermost zone of metamorphism. The albite-chlorite schist facies lies on the northwestern side of the Peach Bottom syncline and is considered to be the stratigraphic equivalent of the oligoclase-mica schist facies of the Wissahickon which lies on the southeastern side of the Peach Bottom syncline.

In the eastern Piedmont of Maryland, Baltimore gneiss is exposed in a series of anticlines, with Setters quartzite and Cockeysville marble exposed on their flanks and Wissahickon oligoclase-mica schist in the synclines. The Wissahickon schist grades upward into the Peters Creek schist, which occupies the Peach Bottom syncline in Baltimore and Carroll counties.

General Geology of the western Piedmont of Maryland

The Peach Bottom syncline crosses the southeastern edge of Carroll County, so that most of this county and the eastern part of Frederick County lie in the western Piedmont belt. As has been noted, the albite-chlorite schist facies of the Wissahickon formation is developed on the northwest side of the syncline, and it covers a wide area in the western Piedmont. The underlying Cockeysville marble and interbedded volcanic rocks are exposed in anticlines in the schist. The age and relations of this infolded series of marbles and metamorphosed volcanic rocks of the western Piedmont of Maryland are the subject of this paper.

Previous Work in the western Piedmont of Maryland

The area has been studied in part by Mathews and Keith, and the results of Keith obtained in the Frederick and Washington quadrangles

and those of Mathews[3] in the western Piedmont of Maryland were expressed by the latter before the Geological Society of America in 1905. Mathews recognized the Peach Bottom syncline and considered that it contains either a less metamorphosed portion of the Wissahickon formation or an infolded younger series, less metamorphosed than the Wissahickon, which lies on either side of it. The belt of Wissahickon schist west of the syncline was described as lying east of a belt of phyllitic rocks associated with surface volcanics and resting on Shenandoah limestone of Frederick Valley type.

In 1910 Mathews,[4] in a general discussion of the geology of the western Maryland Piedmont in "Limestones of Maryland," recognizes the anticlinal character of the marble and superposition of the volcanics on the marble, but concludes "that either the volcanics may be in part Ordovician age, in which case the limestones may represent metamorphosed equivalents of the Shenandoah group, or the volcanics may be pre-Cambrian and overlie the limestones through thrust-faulting, in which case the limestones may be of Loudoun or Shenandoah age."

Recent Work in the western Piedmont of Maryland

General statement

During the last two years the writer has established the following succession of the pre-Cambrian crystalline schists in the western Piedmont of Maryland.

Cockeysville marble

Extent.—The oldest rock of the area is the Cockeysville marble. It enters Maryland from York County, Pennsylvania, and extends southwestward, occupying narrow valleys on either side of Dug Hill Ridge and wider valleys west of Parrs Ridge, near Westminster, New Windsor, and Union Bridge, and to the southwestward.

Lithology.—The marble is a fine-grained cream to white rock, stained pink, purple, or green near the contact with volcanic rocks. It resembles in many respects the Cockeysville marble of the eastern Piedmont, but is finer grained and contains more impurities.

Volcanic rocks

Extent.—In the western Piedmont of Maryland the marble is associated with metamorphosed volcanic rocks, which have been traced from

[3] E. B. Mathews: Correlation of Maryland and Pennsylvania Piedmont formations. Bull. Geol. Soc. Am., vol. 16, 1905.

[4] E. B. Mathews and J. S. Grasty: Limestones of Maryland. Maryland Geological Survey, 1910, p. 359.

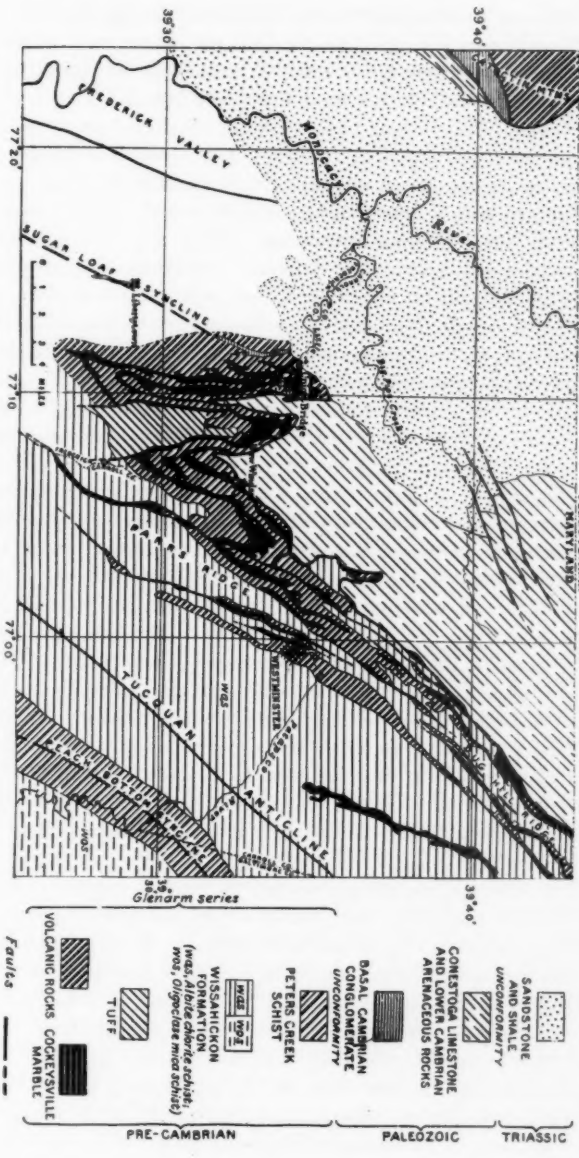

FIGURE 1.—*Geologic Map of the western Piedmont of Maryland*

By Anna I. Jonas.

Pennsylvania 15 miles northeast of this area, through Carroll, Frederick, and Montgomery counties, to the Potomac River west of Washington. Their greatest extent is in Carroll and Frederick counties, south of Westminster, New Windsor, and Union Bridge.

Lithology.—The volcanic rocks consist of altered amygdaloidal basalt, diabase, tuffs, and doubtful rhyolite. The basalt and diabase have been completely recrystallized and are green epidotic amphibolites with the mineral composition, hornblende, chlorite, calcite, epidote, albite, quartz, and magnetite. They comprise both coarse and fine grained varieties possessing a schistosity even in massive members. Much of the basalt is spotted with white amygdules filled with quartz, epidote, or calcite. A schistose variety occurs in which the amygdules are flattened to white or green blebs which show on cleavage planes. This variety is usually blue gray or purple and may be altered rhyolite.

South of Westminster the meta-basalts are interbedded with blue and green schists, which are considered to be altered volcanic ash. These schists are fine-grained aggregates of chlorite and sericite and break into slaty fragments. They contain scanty feldspar which may have been fragments in the original tuff. The blue and green slaty schist increases in importance in the southwestern part of the area.

Relations to the marble and to the Wissahickon schist.—South of Westminster, New Windsor, and Union Bridge, the marble-volcanic series is exposed in three anticlines, with the overlying Wissahickon albite schist in the intervening synclines. Contacts of marble and volcanics show a zone of impure marble, with slaty partings usually 3 to 10 feet thick, lying between massive marble and volcanic rocks. At some localities the impure rock has the appearance of a marble breccia with the fragments of marble cemented in a green slaty matrix. One well exposed contact of volcanics and marble shows 80 to 100 feet of interbedded calcareous slate, marble, and amygdular basalt above 300 to 400 feet of marble.

At no observed contact has the marble surface appeared very irregular, with deep fissures filled with volcanic rock, as would be expected if lava had been outpoured on an old land surface. It seems probable that the volcanic extrusions were submarine and were accompanied by the deposition of fine tuffaceous material. The period of volcanic activity was preceded and followed by the deposition of calcareous beds of the Cockeysville marble, which in turn was covered by other volcanic outpourings before the deposition of the argillaceous arkose that has been recrystallized with the Wissahickon schist. It seems probable that volcanic activity of an explosive character occurred during the deposition

of Wissahickon formation, because in the area south of Union Bridge tuffaceous slates underlie and may be interbedded with the Wissahickon albite schist. Future work in southwestern Carroll County and adjoining areas may throw more light on this subject.

WISSAHICKON ALBITE SCHIST

The albite schist facies of the Wissahickon formation lies on the northwest side of the Peach Bottom syncline, which is occupied in this area by the Peters Creek formation. On the southeast side of Dug Hill Ridge the Wissahickon formation covers an upland area seven miles wide, along the line of the Tucquan anticline, which enters Carroll County from Baltimore County and extends southwest of Carroll County to the Potomac River west of Washington. The albite schist forms hills in synclinal areas between valleys and lower hills underlain by less resistant marble and volcanic rocks. The albite chlorite schist facies of the Wissahickon formation is a chlorite-muscovite schist in which albite occurs in porphyroblasts with ragged boundaries and filled with inclusions. Many layers of the schist lack albites. The chlorite and perhaps finely divided magnetite and hematite grains impart a bluish green color to the rock. Near the base the formation contains a quartzose member which is a schistose vitreous quartzite with blue quartz pebbles and inconspicuous muscovite or biotite.

AGE OF GLENARM SERIES AND VOLCANIC ROCKS

The Cockeysville marble and Wissahickon albite schist are a part of the Glenarm series which unconformably overlies Baltimore gneiss, the oldest pre-Cambrian sediment of the Maryland Piedmont.

From a study of the southeastern part of the Maryland Piedmont, the Glenarm series was thought to be pre-Cambrian, but proof of the suggestion was not there found. In the western Piedmont of Maryland basal Cambrian quartz conglomerate and quartzite lie in a syncline called the Sugarloaf syncline. The conglomerate and quartzite extend 25 miles southwest, in interrupted outcrop, from the edge of the Triassic sandstone west of Union Bridge to the south of Sugarloaf Mountain, where they are again covered by Triassic sediments. West of Union Bridge basal Cambrian quartz conglomerate unconformably overlies volcanic rocks and near Libertytown rests unconformably on Cockeysville marble. The unconformable relation of basal Cambrian sediments to the volcanic rocks and the Cockeysville marble establishes the pre-Cambrian age of these rocks and of the Glenarm series.

PALEOZOIC ROCKS TO NORTH OF THE PRE-CAMBRIAN SERIES

A considerable part of Carroll County, northwest of the area underlain by pre-Cambrian rocks, is occupied by Harpers phyllite, of Lower Cambrian age, and infolded blue slaty Conestoga limestone, of Ordovician age. The area is the southwestern continuation of a larger belt of the same rocks lying to the northeast in Pennsylvania, where the age and relations of these Paleozoic formations were first studied and determined on paleontologic and stratigraphic grounds.

Previous to the present survey of Carroll County the blue slaty limestone was not separated from the pre-Cambrian white marble, but was considered to represent an argillaceous facies of the marble. The blue limestone differs from the marble in lithology, association, and age; it lies in synclinal valleys in Harpers phyllite; it is not interbedded with pre-Cambrian volcanics and is lithologically similar to limestone in Pennsylvania which contains Ordovician fossils. These Paleozoic rocks are separated from the pre-Cambrian crystalline schists by an overthrust fault which has carried the pre-Cambrian mass northwestward over Cambrian and younger rocks. This fault has been traced southwestward 100 miles, from the region north of Philadelphia to the area under discussion.

RELATION OF THE VOLCANICS TO THOSE OF OTHER AREAS

As early as 1892, G. H. Williams[5] recognized the volcanic character of the rocks of South Mountain, previously interpreted as sedimentary. Later Mathews[6] pointed out the close resemblance of the volcanic rocks of the western Piedmont of Maryland to those of South Mountain and Catoctin Mountain. The epidotic amphibolites resemble the Catoctin schist of Keith,[7] which he describes as an alteration of extrusive diabase and basalt. If glassy rhyolites were originally present in the Maryland Piedmont area, metamorphism has completely removed the glassy structures so well preserved in the South Mountain aporhyolites.

Two areas of pre-Cambrian volcanic rocks not previously described have been recently discovered by G. W. Stose and the writer in the Pigeon Hills and Hellam Hills of the Pennsylvania Piedmont. The extent of volcanic rocks in the Pigeon Hills and Hellam Hills is not great, but the types present include all those found in the larger areas of the Maryland

[5] G. H. Williams: Volcanic rocks of South Mountain. Am. Jour. Sci., 3d series, vol. 44, 1892, pp. 482-496.

[6] E. B. Mathews and J. S. Grasty: Limestones of Maryland. Maryland Geological Survey, 1910, pp. 356-357.

[7] Arthur Keith: U. S. Geological Survey Bull. Atlas No. 10.

Piedmont as well as porphyritic rhyolite like that of South Mountain. The occurrence of volcanic rocks in the area of the Piedmont Plateau, extending from near the Susquehanna River, in Pennsylvania, to the Potomac River, indicates that widespread volcanic action took place far east and southeast of the South Mountain and Catoctin Mountain area.

The volcanic rocks of the Pigeon and Hellam Hills and of South and Catoctin Mountain are known to be pre-Cambrian, but they are not associated with any pre-Cambrian sedimentary series, and hence whether they were extruded early or late in pre-Cambrian time has been a matter of inference. The finding of similar and probably contemporaneous volcanic rocks in the lower part of the Glenarm series places the volcanic outpouring in the period of deposition following the erosion of the Baltimore gneiss basement on which the Glenarm series was laid down.

SUMMARY

1. The oldest rocks of the western Piedmont of Maryland are brought to the surface in anticlines along the flanks of Dug Hill and Parrs Ridge and extend west and southwestward to the eastern edge of the Frederick Valley and southward to the Potomac River.

2. These rocks consist of the Cockeysville marble, interbedded with surface volcanics and tuffs and overlain by the albite schist facies of the Wissahickon.

3. The volcanics and Cockeysville marble are overlain unconformably by basal Lower Cambrian quartzites of the Sugarloaf syncline; hence the volcanics and Glenarm series are pre-Cambrian.

4. The pre-Cambrian rocks lie south of an area of Lower Cambrian arenaceous rocks in which are infolds of Conestoga blue slaty limestone of Ordovician age. The line of contact between pre-Cambrian and Paleozoic rocks is the surface trace of an extended overthrust fault.

5. The metamorphosed volcanic rocks of the region resemble pre-Cambrian volcanics of the Pigeon and Hellam Hills and of South Mountain and Catoctin Mountain of Pennsylvania, Maryland, and Virginia and probably represent the southeastern part of a volcanic outpouring that was widespread to the northwest.

6. The volcanic extrusions occur in a pre-Cambrian sedimentary series which is younger than the Baltimore gneiss.

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SAN FELIX AND SAN AMBROSIO: THEIR GEOLOGY AND PETROLOGY [1]

BY BAILEY WILLIS AND HENRY S. WASHINGTON

(*Presented before the Society December 28, 1923*)

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PART I. GENERAL DESCRIPTION AND GEOLOGY; BY BAILEY WILLIS

San Felix and San Ambrosio are volcanic islands in the South Pacific Ocean, San Felix being situated in latitude 26° 15′ south and longitude 80° 7′ west of Greenwich and San Ambrosio lying about 16 kilometers to the east-southeast (figure 1). They are about 500 miles west of Chañaral, on the coast of Chile, and the same distance due north of the group of Juan Fernandez and Mas-a-fuera. The South Pacific charts show several known rocks or islets and some whose existence is recorded as doubtful, which, with the above-named islands, form an archipelago strewn on a narrow submarine ridge that extends along the meridian of 80 degrees west from about 36 degrees south to 26 degrees south, the ridge being defined by the 2,000-meter contour line. Knowing that all these islands and islets are the peaks of volcanoes, we may suspect that there are more of them than we can see; but this must remain an unverified guess until detailed soundings can be made. The depth of the ocean

[1] Manuscript received by the Secretary of the Society March 25, 1924.

in this region, which lies west of the Richards Deep, varies from 4,000 to 5,000 meters. The islands, therefore, represent the summits of volcanoes probably sixteen to eighteen thousand feet or more in height—that is to say, they compare with the great volcanoes of the Andes, which are situated on the other side of the deep.

San Felix and San Ambrosio are the remains of two large, distinct craters. A third crater is (possibly) indicated by Peterborough Cathedral, a precipitous islet about one mile northwest of San Felix. The rocks that rise above the sea are, however, little more than small remnants of the original group, and there is free play for the imagination

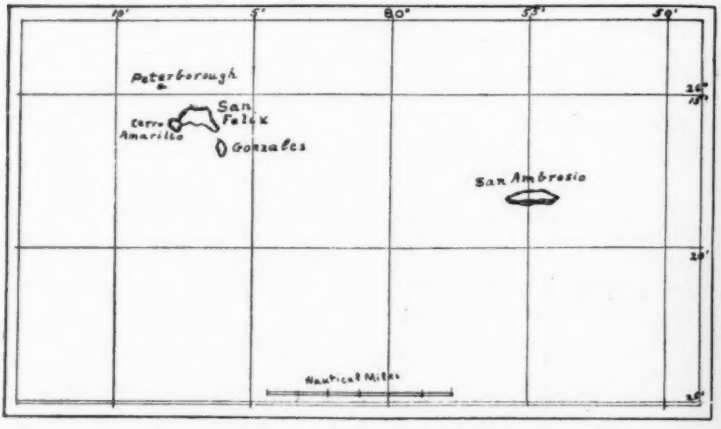

FIGURE 1.—*Map of San Felix and San Ambrosio*

in extending the curves of the crater walls beneath the unbroken expanse of sea in their vicinity.

Having sailed in May, 1923, from Chañaral, the nearest port in Chile, I approached San Ambrosio from the east practically end on. It is an imposing rock, rising on its southern side 254 meters in a sheer precipice from the surf and sloping northward to cliffs that are in general 100 meters high along the northern shore (figure 2).[2] The width of the island is but 800 meters and it is only 3 kilometers long. The chart gives its highest elevation as 1,500 feet. There is little in its somewhat oval form to suggest the curve of a crater, but the obvious slope of the upper surface from south to north, and of the bedded lavas of which it is formed, indicates that the crater was south of the existing fragment

[2] The photographs are by Bailey Willis.

of the rim. On nearer approach, in circumnavigating the island, a very large number of distinct lava-flows are recognizable and many vertical dikes cutting through the flows can be made out. The volcanic structure is obvious.

It is possible to land on San Ambrosio at one point, Covadonga Cove, which is nothing more than a niche in the cliffs, with just room for a moderate-sized rowboat. There, in good weather, skillful seamen may effect a landing, and from that point the cliffs have been climbed. The summit plateau is frequently covered with mist, condensed from the air currents that ascend along the southern cliffs, and is therefore covered with vegetation, consisting, according to reports, of low, spreading shrubs (*Thaumoseris* n. g. *lacerata Ph.*).[3]

FIGURE 2.—*San Ambrosio from the West*

I did not myself land on San Ambrosio and am indebted to Captain Stuart D. Campbell for a specimen of the lava taken from the foot of the cliffs at Covadonga Cove.

The island of San Felix (figure 3), unlike San Ambrosio, is a low platform, forming a crescent and ending in two rounded hills. At the northwest extremity the so-called Cerro Amarillo is 183 meters high and of a deep yellow color, due to the decomposition of the basic tuff of which it is composed. At the other, the southeastern extremity, is a similar hill of the same material, 132 meters high, which is known as Islota Gonzales (figure 4). It is separated from the main island by a breach,

[3] Report of an exploration of the islands of San Felix and San Ambrosio by the frigate *Covadonga*—Don Ramon Vidal Gormaz, captain—1875.

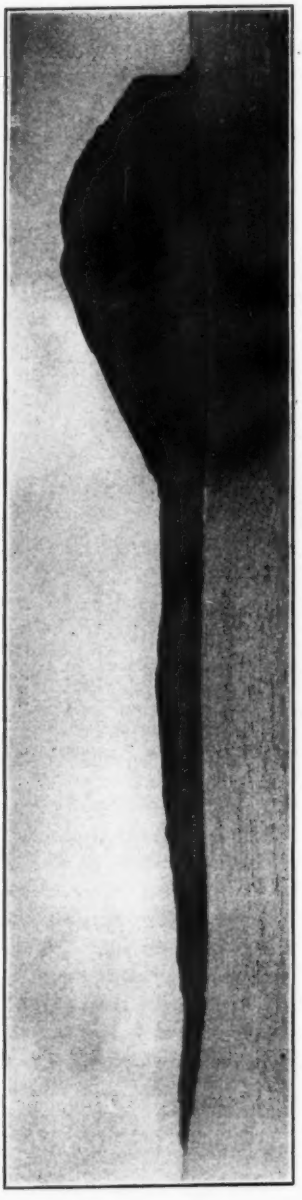

FIGURE 3.—*San Felix from the North*
Cerro Amarillo on right, landing place in center, lava-flows to left.

where the breakers roll over the scarcely submerged rocks. The intervening platform, which stretches between Cerro Amarillo and Islota Gonzales, has an altitude of 60 to 70 meters in the cliffs along the southern, inner, side of the crescent and of 15 to 20 meters along the northern coast. The total length of the curving island and islet between the extremities is about 5 kilometers, and that of the island of San Felix is but 3. The width of San Felix varies from 500 to 1,000 meters.

In approaching San Felix from San Ambrosio—that is, from the southeast—one is struck by the difference in form between the rounded hills at the extremities and the flat table between them. The difference in color is also notable, the hills being bright yellow, whereas the table is jet black. On closer examination it is apparent that the yellow tuff is the older and the black lava is the younger of the two.

It seems worth while here to introduce the story of a change of opinion that was forced on me by the actual relations of the rocks as contrasted with those which seemed to be apparent, in the view from a distance. I approached San Felix with certain preconceptions connected with the earthquake of November 10, 1922, and suggested by the accounts of the island given me by Captain Campbell, who had visited it in October, 1922, and

again in February, 1923. In the latter visit the aftershocks of the great earthquake were frequent and severe during the four days the Captain spent in the vicinity of the island and on it. He was overcome by volcanic gases on ascending to the platform with the intention of climbing Cerro Amarillo, and he had become convinced that the volcano was an active center in which the earthquake had originated. His account was very circumstantial and so fitted in with general facts of volcanic phenomena that I expected to find evidences of recent eruption.

In approaching the island, we sailed around the southern side with a leeway of about a mile from the two extremities of the crescent, and we

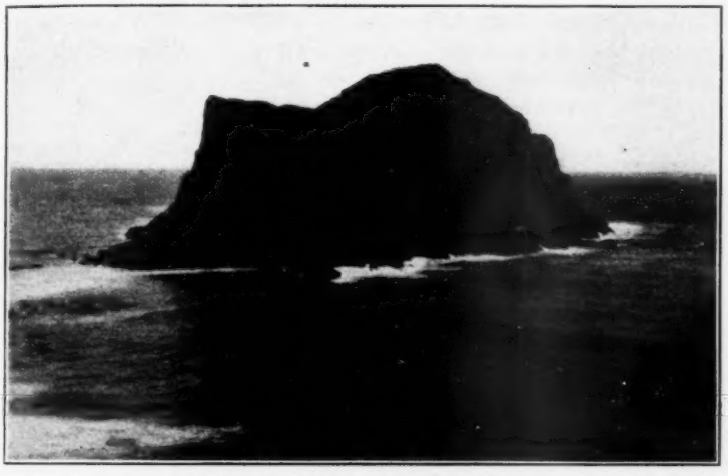

FIGURE 4.—*Islota Gonzales from West*

Black lava on left, yellow tuff on right.

could clearly see the surf dashing high on the cliffs of the black platform. Captain Campbell had told me that he and his sailors had seen a dull red glow on the summit of Cerro Amarillo, when anchored some eight or ten miles distant. I therefore examined the peak for evidences of eruption. The top was cup-shaped and within it lay a mass of black lava from which small streams had run down the cliffs to the sea. No one who examined it from that distance could reasonably doubt that it was a very recent, though small, local eruption. It might even still be hot.

On the following day, with several officers of the naval vessel, which the Chilean Government had courteously put at my service for the trip, I climbed Cerro Amarillo, keeping well to windward of possible gas

emanations. My chagrin may be imagined when I found small bushes growing on the supposed hot lava, and was forced by a study of its relations to recognize it as a splash from the old crater which had been thrown up on the yellow tuff and had run back into the crater at the time of the eruption of the black table lava.

It had been reported in perfect good faith that San Felix was shaken by the earthquake, and that its eastern end was broken off and had sunk beneath the sea, and that it was the center of violent convulsions. It shows cracks attributable to the earthquake, but the rest of the statement is as much the work of imagination as was the recent eruption of which I thought that I saw evidences. The island is volcanic and it is probably not many centuries since the eruption of the black lava. Volcanic gases were still issuing from a crevice in the southern rim in May, 1923, and they were reported by Captain Campbell and by the sailors who accompanied him in February as having been sufficient in volume to overcome him.

The bird life of the island, which many visitors have described as exceedingly abundant, had either been destroyed or driven away. I counted twenty-five live birds and fifty dead ones on the entire island, where formerly there must have been many thousands. It is probable that most of those that were killed were eaten by other birds and by insects, and that their light bones and feathers were blown from the unprotected rocks into the sea. The large colony of lobsters which lived on the reefs around the island and which formed an attraction that drew fishermen like Captain Campbell to it had been destroyed, leaving but few survivors. A Spanish diver, Mauricio Pardesano, who was with Captain Campbell on his two fishing expeditions and who also accompanied me, stated that the sea-floor was covered with the carapaces of dead lobsters. Captain Campbell and Pardesano independently stated that during their visit in February the ocean water was tepid, distinctly warm. They said that it was warmer immediately succeeding each one of the repeated earthquake shocks, and Pardesano found it much warmer on the bottom than at the surface.

These facts all point to considerable emanations of gas at the time of the great earthquake and during the succeeding months. In May, as already stated, some gas was still issuing from a crevice along the southern cliffs of the island, as was shown by the sulphurous smell and puffs of blue vapor observed by me and by the Chilean officers. In this sense and to this extent we may consider San Felix an active volcano.

The date of the latest eruption, that of the black lava, is a matter of considerable interest, but we are forced to set it prior to the discovery of

the island, in 1574, because there seems to have been no change in the general configuration of the group since Juan Fernandez first discovered it. Were this fact not unquestionable, one would not suppose the black lava to be 350 years old or more. Its surface still shows the distinct forms of pahoehoe, the glistening surfaces and the ropy eddies of recently cooled slag. One is not surprised that there is no soil, for the winds blow everything but coarse sand from the rocks, but as one walks over the irregular surface of the old flow it is very difficult to believe that it is actually as old as it must be. When, however, I ascended to the cliffs of the southern side and looked from them over the site of the old crater from which the lava must have flowed, it was less difficult to realize its antiquity. At least three-fifths of the crater wall is gone and the ocean

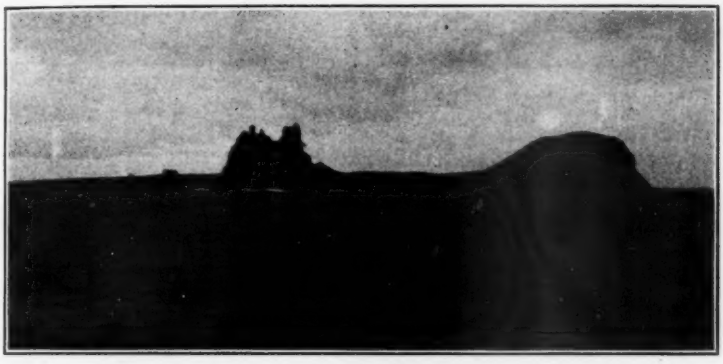

FIGURE 5.—*Peterborough Cathedral from the Northwest*

San Felix is seen behind it.

rolls over its foundations. The southern crater wall must have existed and have stood at a height greater than that of the remaining remnant or the lava would not have poured out where it did. Whether the missing part was blown up, or melted down, or faulted off, one may guess according to one's inclinations; there is no evidence one way or the other.

Not only is the crater wall of greater San Felix lost beneath the ocean, but an even larger part of the old crater of San Ambrosio is gone and the Cathedral of Peterborough is a central remnant, a volcanic neck of a third lost crater.[4]

The Cathedral of Peterborough (figure 5) is a very striking rock, a

[4] It seems to be possible, judging from the soundings given on the chart and from its columnar structure, that Peterborough is a parasitic cone of San Felix or more probably the end of a massive flow from this crater.—H. S. W.

FIGURE 6.—*The Lava Field of San Felix as seen from Cerro Amarillo*
Islota Gonzales is at right, with old crater in the right-hand bay. Steam was issuing from the cliffs of this island near the left end of surf. San Ambrosio is seen in the background.

group of columns rising about fifty meters above the sea, pierced through by the waves and surrounded by reefs that seem to represent other columns that have fallen. It is practically inaccessible, but its dense, black, jointed, columnar masses leave little doubt that it is a basaltic, volcanic neck.

I spent two half-days on San Felix and recognized three distinct types of rock of as many different periods of eruption. The youngest is the black lava which forms the platform of the island (figure 6). It very distinctly overlies and is splashed up on the yellow tuff, both at Cerro Amarillo and at Islota Gonzales. The contact is easily observed at the landing place, where a cavern has been worked out of the rock. In the adjacent cliffs one may count fifteen or more distinct layers (flows), all of the same dense, black, vesicular lava, which is so uniform in appearance from end to end of the island that I was convinced that it was all of one and the same erup-

tion. I was, therefore, satisfied to collect specimens from one locality only, namely, from the upper 10 or 15 feet of the black cliff immediately above the landing, and I would suppose that any differences in the chemical composition, such as have been found in the specimens, may be explained as differences in the somewhat considerable volume of the magma.

The next older lava is the yellow tuff which forms the Cerro Amarillo and the peak of Islota Gonzales. In Cerro Amarillo the structure is that of concentric layers, which strongly suggest those that are seen on a smaller scale in the cone that forms around a small orifice in larger craters. The layers are steeply inclined and concentric to the cone, on the north side all around from east to west; on the southern side they are

FIGURE 7.—*Bedded yellow Tuffs of Cerro Amarillo*

less complete (figure 7). I do not feel sure, however, that these are original structures. The rock is greatly decomposed and the bedded structure might be due to chemical reaction and increase of volume. The latter suggestion is strengthened by the fact that they are very thin, but a few inches to a foot in thickness, and there seems to have been no crater from which the tuffs could have been extruded to form an individual cone. If, as seems most probable, the yellow tuff of Islota Gonzales is identical with that of Cerro Amarillo, they were both erupted from the intervening crater, and the conical structure of Cerro Amarillo would be secondary rather than original.

The third type of rock on San Felix is a light gray trachyte, which exhibits a very thinly laminated structure and strikingly suggests a schist. It occurs in fragments up to a foot in diameter in the yellow

tuff of Cerro Amarillo and was obviously torn off from some deeper mass and brought up with the tuff. The schistose structure is so striking that I did not suspect the volcanic nature of the rock and framed some entertaining hypotheses of a continental platform or submarine fault. I am not sorry that they have been destroyed, for I do not think that our European colleagues need any encouragement in the discovery of lost continents.

The trip to San Felix was undertaken in connection with the great earthquake that shook northern Chile on the tenth of November, 1922. The immediate incentive was found in the reports of Captain Campbell, who on his return from the islands in February wrote me regarding his experiences. The basic facts were as he saw them, so far as I was able to judge, even though his fancy suggested inferences that proved to be exaggerated. It seems evident that the earthquake shook not only Chile, but also the other side of the great deep, 500 miles off the coast. It also broke cables at a depth of 1,200 fathoms in the intervening depression, and it shook down buildings in mining towns 100 miles east of the coast; that is to say, the width of the zone of recognized activity is 600 miles. From south to north the earthquake was distinctly felt through twenty degrees of latitude, from Concepcion to Iquique, approximately 1,400 miles. In other words, it was so extensive that it could not be attributed to any local center of activity, such as a volcano, but may rather be classed as a regional phenomenon expressed in the elastic vibration of an enormous mass of rock underlying the great deep off the Chilean coast.

Part II. Petrology; by H. S. Washington

General statement

The specimens entrusted to me by Professor Willis for study represent the three kinds of rock that were observed by him to occur on San Felix. It would appear, from the few chemical analyses that I have made, that the trachytes are rather uniform in general composition, whereas the later flows of basalt that make up the midway plateau differ somewhat more widely in their characters; so that further collections from different points on the island, especially from the latest splash of lava that has been described by Willis, and from the upper and the lower flows, would be very desirable. The specimen of lava from San Ambrosio that was given to Professor Willis by Captain Campbell arrived since the time of writing, and the results of the study of it are given in an appendix (page 383).

TRACHYTE

General statement.—There are two varieties of the trachyte that occurs as blocks in the yellow tuff of Cerro Amarillo; one is very schistose and typically holocrystalline, the other is massive and decidedly vitreous. The two types appear to differ slightly in chemical composition, but less so in their mineral characters.

Schistose trachyte.—The variety of trachyte that seems, from the description by Willis and from the specimens collected by him,[5] to be the more abundant is medium gray, densely compact, aphanitic, and aphyric; none of the specimens is vesicular. The rock is markedly, but variably, schistose. Some of the specimens split readily into thin, fairly smooth plates, whereas in others this character is less pronounced, but is still evident. The schistosity of most of the specimens is so prominent that both of the authors were led, on a first inspection, to think that the rock was a metamorphic schist.

In thin-section the rock shows a somewhat peculiar trachytic texture, which resembles that of the trachyte of Mas-a-fuera described by Quensel,[6] that of Puu Anahulu on the Island of Hawaii,[7] and of the trachyte of Lahaina on Maui.[8] The texture seems to be rather usual in the trachytes of the Intro-Pacific volcanic islands. Ill-defined laths of alkali feldspar make up most of the rock. For the most part these are arranged irregularly, but here and there flow texture is evident. A considerable number of the feldspar laths are somewhat shorter and thicker; these are uniformly dull and cloudy, as if from kaolinization, although the very small amount of water shown in the analysis is opposed to this explanation. But they are of different chemical composition from the longer, thinner, clearer, and more numerous laths, whose optical characters indicate that they are more sodic. Many very small prismoids of colorless pyroxene, which is presumably acmite, almost without diopside, judging from the chemical analysis, and minute grains of magnetite are scattered through the rock. A scanty, colorless, isotropic or feebly birefringent base is probably the nephelite that is shown in the norm.

An analysis of a moderately schistose specimen is given in number 1 of Table I. It is that of a dominantly sodic trachyte, such as is associ-

[5] There are four specimens of this variety and one of the other.

[6] P. D. Quensel: Die Geologie der Fernandezinseln. Bull. Geol. Inst. Upsala, XXX, vol. 11, 1912, p. 283.

[7] Whitman Cross: An occurrence of trachyte on the Island of Hawaii. Jour. Geol., vol. 12, 1904, p. 510; and Lavas of Hawaii and their relations. U. S. Geol. Survey Prof. Paper 88, 1915, p. 35. H. S. Washington: Petrology of the Hawaiian Islands. II, Hualalai and Mauna Loa. Am. Jour. Sci., vol. 6, 1923, p. 106.

[8] Whitman Cross: Lavas of Hawaii and their relations. U. S. Geol. Survey Prof. Paper 88, 1915, p. 26.

ated with highly sodic, nephelite-bearing rocks in many well known comagmatic regions. The high alkalies and the high ratio of ferric oxide to ferrous, the latter characteristic of holocrystalline as opposed to hyaline lavas, are the most notable features, and the rather high zirconia is a minor feature of some interest. The norm (Table III, number 1) shows a small amount of diopsidic acmite and of nephelite. The average feldspar is a decidedly sodic orthoclase. It is probable, as has been remarked, that the stout cloudy feldspars are of potassic orthoclase, whereas the more numerous clear, thin, and longer tables are of a more sodic anorthoclase than the average.

The great similarity between this trachyte and those of other Intro-Pacific islands is shown by the analyses of such lavas that are cited in Table I for comparison. They will be discussed later.

Hyalo-trachyte.—One of the specimens of trachyte from Cerro Amarillo is of a type rather different from that just described. This rock is much darker gray, and it shows many minute glistening faces of feldspar in a dense, very dark gray, aphanitic groundmass, which has the subresinous luster characteristic of many vitreous lavas. There is only a very slight tendency to schistosity in this specimen; the fracture is generally even, but parallel to one plane the fracture surface is slightly wavy, made up of narrow, parallel, low, rounded ridges, like a slightly crumpled schist.

The thin-section shows some small phenocrysts of orthoclase, as sharply defined, well shaped, thick tables, many of which are twined according to the Carlsbad law. These appear to be of orthoclase that contains little or no soda, which was the first mineral to crystallize. There are present also rather more numerous, less well bounded, thinner, and longer tables of a more sodic feldspar. These feldspars lie, with marked flow texture, in a base of light brown glass, which itself shows flow texture in streaks of slightly darker material. Very few, minute crystals of olivine are present, which for the most part are seen clearly only under high powers. Grains of magnetite are very rare and no pyroxene is present.

The chemical composition of this trachyte (number 2, Table I) differs from that of the schistose type chiefly in the lower silica and soda, the higher ferrous oxide, and the slightly higher magnesia and lime, although these differences change the position of the rock in the quantitative classification only in the subrang. Phosphorus pentoxide is rather high, a feature that seems to be characteristic of many of the lavas of the Intro-Pacific volcanoes. The norm (Table III) shows the presence of a little nephelite but no pyroxene. There appear to occur in the Pacific fewer analogues of this type of trachyte than of the other.

TABLE I.—*Analyses of Trachytes*

	1	2	3	4	5	6
SiO_2	62.54	58.22	63.43	62.02	61.90	58.84
Al_2O_3	18.33	18.31	18.64	18.71	18.37	20.30
Fe_2O_3	2.11	2.63	2.78	4.30	2.46	2.74
FeO	0.82	1.91	1.02	0.10	0.66	0.64
MgO	0.33	0.97	1.38	0.40	0.46	0.60
CaO	0.92	1.52	1.68	0.86	0.58	1.66
Na_2O	8.02	6.14	6.77	6.90	7.95	7.48
K_2O	5.70	5.78	3.82	4.93	5.36	5.72
H_2O+	0.15	1.47	0.24	0.80	1.52	0.68
H_2O-	0.05	0.86		0.31	0.61	0.31
CO_2	none	none	n. d.	none	n. d.	n. d.
TiO_2	1.24	0.92	0.28	0.31	0.20	0.72
ZrO_2	0.12	n. d.	n. d.	0.06	n. d.	n. d.
P_2O_5	0.13	0.90	0.18	0.24	0.01	0.13
Cl	n. d.	n. d.	0.04	none	n. d.	n. d.
S	0.03	n. d.	0.01	0.02	n. d.	n. d.
Cr_2O_3	none	n. d.	n. d.	none	trace	0.02
MnO	0.15	0.16	0.09	0.15	0.26	0.12
BaO	none	n. d.	n. d.	0.02	n. d.	0.07
	100.64	99.79	100.36	100.13	100.34	100.03

1. Schistose trachyte, blocks in tuff, Cerro Amarillo, San Felix. H. S. Washington, analyst.

2. Hyalo-trachyte, blocks in tuff, Cerro Amarillo, San Felix. H. S. Washington, analyst.

3. Trachyte, Mas-a-fuera, Juan Fernandez Islands. Sahlbom, analyst. P. Quensel, Bulletin of the Geological Institute of Upsala, volume 11, 1912, page 283.

4. Trachyte, Puu Anahulu, Hualalai, Hawaii. Washington, analyst. H. S. Washington, American Journal of Science, volume 6, 1923, page 108.

5. Nephelite trachyte, Mauratapu, Huahine, Society Islands. Morley, analyst. Iddings and Morley, Proceedings of the National Academy of Sciences, volume 4, 1918, page 114.

6. Phonolite, Vaitia, Taiarapu, Society Islands. Morley, analyst. Iddings and Morley, loco citato.

NEPHELITE BASANITE

The "basalts" of the low middle portion of San Felix appear megascopically to be quite uniform, but the specimens collected by Willis show, chemically, considerable variation. They are all dense, black, mostly aphanitic and almost aphyric lavas. Most of the specimens are of typical pahoehoe, fresh and with the characteristic corded surfaces and finely uniform vesiculation of this form of lava. These have rather sparse, very small phenocrysts of dark green olivine scattered through a dense, aphanitic, slightly brownish black groundmass, which has a subresinous

luster. One specimen comes from what appears to be a flow of aa lava; at least the vesiculation is of the kind with few irregularly shaped and rather large vesicles. This is very dark gray, not the jet black of the pahoehoe specimens, and contains some small phenocrysts of yellow olivine in a dense aphanitic groundmass that has a dull stony luster without any resinous quality.

The thin-sections of all these basalts are very unsatisfactory for study, because, even if very thin, they are so black, dense, and opaque that very little of their texture or mode is visible. Both types show some small (up to 1 millimeter), well formed phenocrysts of fresh olivine, which is entirely free from inclusions. There are no phenocrysts of feldspar, pyroxene, or other minerals. The groundmass in the pahoehoe specimens is black and almost perfectly opaque, the thin edges alone showing slight indications of the presence of extremely minute feldspar needles and small prismoides of pyroxene embedded in a brown dusty glass. These are seen rather better in the specimen of aa, which is slightly more crystalline than the pahoehoe, but the feldspar needles are too minute for satisfactory identification of the kind of plagioclase. No trace of flow texture is visible in any of the thin-sections.

TABLE II.—*Analyses of Nephelite Basanite and Basalt*

	1	2	3	4	5	6	7
SiO_2	46.22	43.20	43.47	43.37	46.43	44.74	43.76
Al_2O_3	12.29	8.51	17.30	8.48	10.91	16.74	11.58
Fe_2O_3	2.14	3.49	6.87	2.91	3.15	3.70	4.39
FeO	7.91	7.84	7.09	11.00	10.26	8.53	7.57
MgO	7.55	12.04	8.60	25.93	11.08	4.80	12.97
CaO	8.94	10.21	6.09	5.03	10.09	9.88	9.64
Na_2O	4.04	5.07	2.53	1.33	3.16	4.42	3.03
K_2O	3.33	0.69	0.74	0.58	0.54	1.14	1.84
H_2O+	0.08	0.78	3.46	0.19	0.66	1.12	0.47
H_2O-	0.04	0.71		....	0.15	0.33	....
TiO_2	5.86	6.78	2.68	1.03	2.59	3.68	3.41
ZrO_2	0.02	n. d.	n. d.	n. d.	none	n. d.	n. d.
P_2O_5	1.12	0.58	0.27	0.19	0.67	0.70	0.45
Cl	n. d.	n. d.	0.18	0.08	n. d.	n. d.	n. d.
S	0.02	n. d.	0.12	trace	0.07	n. d.	n. d.
Cr_2O_3	0.05	n. d.	n. d.	n. d.	none	trace	n. d.
MnO	0.17	0.15	0.07	0.13	0.09	0.19	n. d.
BaO	none	....	n. d.	n. d.	none	n. d.	n. d.
	99.78	100.05	99.60	100.25	99.85	99.97	99.72

1. Nephelite basanite (pahoehoe), San Felix. Washington, analyst.
2. Nephelite basanite (aa), San Felix. Washington, analyst.

3. Nephelite basanite, Mas-a-fuera, Juan Fernandez Islands. Sahlbom, analyst. Quensel, operi citato, page 280.

4. Picrite basalt, Mas-a-fuera. Sahlbom, analyst. Quensel, opus citato, page 287.

5. Olivine basalt, lava of 1801, Hualalai, Hawaii. Washington, analyst. H. S. Washington, American Journal of Science, volume 6, 1923, page 102.

6. Nephelite basalt, Tapahi, Tahiti, Society Islands. Foote, analyst. Iddings and Morley, Proceedings of the National Academy of Sciences, volume 4, 1918, page 115.

7. (Nephelite) basalt, Matavanu Volcano, Savaii, Samoan Islands. Heussler, analyst. Klautsch, Jahrb. Preuss. Geol. L.-Anst., volume 27, 1910, page 174.

Two analyses were made of these "basalts," one of a very fresh, corded pahoehoe (Table II, number 1), the other of the specimen of aa (Table II, number 2). Although they resemble each other in their most general features, there is considerable difference between them. The low silica and alumina and the high soda show that they are not analyses of ordinary basalts, and the norms (Table III) indicate that much nephelite would have been present had they been fully crystallized. The norms indicate also that the feldspar is, in general, oligoclase or even more alkalic, and the norm of number 2 shows a small amount of acmite, indicating an excess of soda. The presence of such highly sodic feldspar in rocks that are so femic is somewhat unusual. The percentage of titanium dioxide is very high in both rocks, as is also that of phosphorus. The former feature appears to be general among the more femic lavas of the Pacific, while high phosphorus is common in the more feldspathic ones.

TABLE III.—*Norms of San Felix Rocks*

	1	2	3	4
Or	33.92	34.47	19.46	3.89
Ab	49.51	48.99	14.67	12.05
An	....	1.95	5.84	....
Ne	6.96	1.56	10.51	15.05
C	....	1.22	....	....
Ac	4.63	....	....	2.77
Di	1.72	....	24.61	36.66
Ol	....	1.68	7.52	10.10
Mt	....	3.71	3.02	3.71
Il	2.28	1.82	11.25	12.92
Hm	0.48	....	....	....
Ap	0.34	2.02	2.69	1.34

1. Schistose trachyte, number 1, Table I, I(II).5".1."4.
2. Hyalo-trachyte, number 2, Table I, I(II).5.1.3(4).
3. Nephelite basanite, number 1, Table II, III.6."2.(3)4.
4. Nephelite basanite, number 2, Table II, IV.2.2.2".2.

TUFF

The tuff that makes up Cerro Amarillo, and presumably Islota Gonzales also, is dense, compact, and very coherent, breaking with an uneven fracture. It can be readily scratched, but not cut, with a knife-blade. Its color is a rather deep, yellow-orange, about the "cinnamon" of Ridgway (15″); the luster is dull and earthy. Throughout the mass are scattered many small (from 1 millimeter to 1 centimeter), usually rounded fragments of a jet-black substance, with a vitreous luster, which study of the thin-section shows to be a basaltic glass. None of the specimens brought back by Willis shows the platy parting noted by him in the mass.

The thin-sections show that the tuff is composed for the most part of a bright orange-yellow, opaque or subtranslucent, indefinite substance, partly in somewhat rounded or irregular areas, with narrow veinlets of calcite between them here and there. Small crystal fragments of olivine are not very numerous; there are rare small black grains of magnetite, but no definite crystals of either feldspar or pyroxene are present. The black basaltic inclusions consist very largely of a light yellowish brown glass, in which are scattered many sharply formed crystals and fragments of colorless olivine, which contains few very minute grains of magnetite. In the thinner parts of the glass base can be seen, somewhat vaguely, very small thin prisms of a colorless, transparent mineral, with oblique extinction, which is considered to be pyroxene. No crystals of feldspar could be definitely made out. The glass is finely vesicular, with many small rounded vesicles, some of which are filled with secondary calcite. The basalt resembles the very glassy nephelite basanites already described, except that the glass base of the fragments in the tuff is much lighter brown and far more transparent, without the abundant black dust of the flow material and with minute microphenocrysts of pyroxene rather than of feldspar in the glass base. An analysis of these fragments would be of interest. The contacts between the basaltic fragments and the yellow tuff base are sharp. The yellow tuff is probably a lithic, devitrified, and somewhat decomposed tuff[9] of the glassy basalt of the fragments, which approaches the nephelite basanites in composition.

An analysis was made of a typical specimen of the yellow tuff, the results of which are given in Table IV, number 1, with some of the very few usable analyses of basaltic tuffs that are to be found in the literature. The analysis is notable chiefly for the high alkalies, in which respect (as well as in the low alumina) it is in marked contrast with the other

[9] L. V. Pirsson: The microscopical characters of volcanic tuffs—a study for students. Am. Jour. Sci., vol. 40, 1915, pp. 201-208.

analyses, which are of basaltic tuffs. The high titanium dioxide and phosphorus pentoxide may also be mentioned. These three features, as we have seen, are characteristic of the analyses of the black, highly vitreous, nephelite basanites that make up the flows of San Felix. This correspondence in certain chemical features gives additional weight to the supposition, already suggested by the presence of the fragments of brown hyalo-basalt, that the yellow tuffs of San Felix are derived from nephelite basanite; they are certainly not derived from ordinary basalts, as the analyses in Table IV render evident.

TABLE IV.—*Analyses of Tuffs*

	1	2	3	4	5	6	7
SiO_2	36.35	39.00	47.43	34.39	37.82	43.48	45.18
Al_2O_3	8.14	15.58	17.20	13.05	13.16	9.74	10.55
Fe_2O_3	5.57	6.13	4.20	5.20	14.11	6.66	2.85
FeO	3.50	3.11	5.27	0.98	0.14	4.19	7.90
MgO	9.05	6.55	4.85	8.62	11.75	10.83	9.90
CaO	7.44	6.82	7.56	18.52	13.39	8.90	9.68
Na_2O	4.70	3.22	3.53	2.56	1.66	5.62	4.61
K_2O	3.25	0.59	1.51	0.24	1.49	3.89	2.03
H_2O+	4.01	6.03	2.42	3.72	....	....	....
H_2O-	8.35	8.18	3.12	2.22	....	....	....
CO_2	4.00	1.83	none	10.89	5.56	....	....
TiO_2	4.76	2.59	3.00	0.63	n. d.	5.70	6.38
P_2O_5	0.83	n. d.	n. d.	n. d.	0.82	0.99	0.86
MnO	n. d.	n. d.	n. d.	n. d.	0.24	....	....
	99.95	99.63	100.09	101.09	100.41	100.00	100.00

1. Yellow basanite tuff, Cerro Amarillo, San Felix Island. Washington, analyst.

2. Yellow basalt tuff, Monte Pozzolana, Linosa Island. Washington, analyst. Journal of Geology, volume 16, 1908, page 29.

3. Gray basalt tuff, Monte Levante, Linosa Island. Washington, analyst. Loco citato.

4. Basalt tuff, Copper Island, Commander Islands, Bering Sea. Staronka, analyst. Morozewicz, Com. C. Russ., Mem. 72, 1913, page 73.

5. Basalt tuff, Punch Bowl, Oahu, Hawaiian Islands. Lyons, analyst. American Journal of Science, volume 2, 1896, page 427. Ignited before analysis; includes 0.15 SO_3, 0.05 FeS_2, 0.07 CuO.

6. Yellow tuff, San Felix, calculated free from H_2O and CO_2.

7. Mean of nephelite basanites of San Felix, calculated free from H_2O and CO_2; minor constituents neglected.

If it be assumed that the water and carbon dioxide of the tuff are in large part addition products, and that there has been relatively little loss of the original material, and the analysis is recalculated to 100 per cent on a water-free and carbon-dioxide-free basis, the figures shown in number 6 of Table IV are obtained. Comparison of these with the fig-

ures of the two analyses of San Felix nephelite basanite given in Table II shows the remarkable correspondence. In the tuff ferric oxide is higher relatively to ferrous because of oxidation, but the mean of the chief constituents of the two nephelite basanites is remarkably like the recalculated analysis of the tuff, as will be seen on comparing numbers 6 and 7 of Table IV.

GENERAL CONCLUSIONS

It would appear from the specimens brought back by Willis that the lavas of the San Felix volcano are, so far as known, of only two kinds—a decidedly sodic trachyte and somewhat variable nephelite basanite, which seems to be uniformly highly vitreous. There is little doubt that the yellow tuff is derived from nephelite basanite magma closely similar to that of the flows. The prominent characteristic of these two types of lava is their high content in alkalies, especially in soda, while high titanium and phosphorus appear to be other constant characters of minor, but still considerable, interest. This conclusion as to the generally highly sodic character of the San Felix lavas is subject to the limitations imposed by the absence of specimens from the lower flows and from various parts of the island. Such basaltic lavas, especially if highly vitreous, may appear megascopically to be very uniform and yet be modally and chemically very diverse. It is, therefore, possible that the earlier, lowermost flows are less sodic and more typically basaltic than the upper, which were the ones examined.

In this predominantly highly sodic character of its lavas San Felix appears to differ widely from other Pacific islands. At Mas-a-fuera, it is true, both soda trachyte and nephelite basanite, closely like those of San Felix, occur, but these are accompanied by basalt and picrite basalt, whereas at the neighboring Juan Fernandez the lavas appear to be, to judge from Quensel's descriptions, only olivine basalt, with neither trachyte nor basanite. Trachyte, also highly sodic, occurs at several other Pacific volcanic islands, as do also nephelite basanite and similar rocks high in soda; but at all of them the predominant lavas are more or less normal basalts or andesites; so that the general magmatic character is basaltic—that is to say, sodi-calcic, somewhat modified by distinctly sodic facies. But this is not the place for a general discussion of the Intro-Pacific lavas, and reference may be made to papers by Lacroix,[10] Marshall,[11] and Iddings.[12]

[10] Lacroix: Les roches alcalines de Tahiti. Bull. Soc. Géol. France, vol. 10, 1910, p. 120.

[11] Marshall: The geology of Tahiti. Trans. New Zealand Inst., vol. 47, 1915, p. 361.

[12] Iddings: The petrology of the South Pacific Islands and its significance. Proc. Nat. Acad. Sci., vol. 2, 1916, p. 413.

One further point may be briefly spoken of. From the field observations made by Willis, especially the inclusion of the trachyte blocks in the yellow tuff and the relations of the tuff and the basanite flows, it would appear that the trachytic lavas at San Felix were earlier, in the sense that lavas of trachyte had been poured out and consolidated before those of basanite, which they must underlie.

At Mas-a-fuera Quensel noted that the trachyte occupies the higher parts of the island, while the basalt and basanite flows lie below them on the lower parts. He argues from this that "there had taken place in the volcanic throat a differentiation according to specific gravity." It is somewhat difficult to follow the reasoning of Quensel, because, if the (supposedly) liquid trachytic magma formed a layer above that of the heavier basaltic magma in the volcanic throat, one might reasonably expect the trachytic flows to have been the first to have been extruded, and so to have formed the lower parts of the volcano, whereas the lower-lying basaltic magmas would have followed these and hence have formed the upper parts of the volcano. Without fairly detailed field observations as to whether the various types of lava issued from lateral vents at different elevations or overflowed the crater edges, it is impossible to discuss such occurrences with intelligence, and in the absence of such observations any generalizations based on such supposed "sequences" appear to us to be premature. In any case, the sequence at San Felix appears to be contrary to what Quensel imagines it to have been at Mas-a-fuera.

It should be said, furthermore, that in these and all such cases we have under our observation only the extreme uppermost tip, an almost infinitesimal part, of a colossal volcano, comparable with the giants of the Andean line, and of which we know, and can know, little or nothing of its lower lavas. It behooves us, therefore, to be cautious in our generalizations, or, still better, to abstain from them until more data are available.

APPENDIX: BASALT OF SAN AMBROSIO

Since the preceding pages were put into type, the specimen of basalt collected by Captain Campbell on San Ambrosio has come to hand, and thin-sections and a chemical analysis of it have been made. It turns out to be an olivine-free basalt, containing a little orthoclase and nephelite, similar chemically to the specimen of pahoehoe from San Felix, the analysis of which is given in number 1 of Table II.

The rock is very dark gray, almost black, very dense and fine-grained, and entirely without vesicles. It is probably from the interior of a thick aa flow. No phenocrysts of any kind are present. Thin-sections show that it is made up largely of a peculiar augite in very small equant anhedra or thin prisms. The color of the augite is somewhat variable;

mostly gray with a slightly purplish tone, partly yellowish or light brownish through incipient alteration. Small, thin plates and laths of multiply twinned plagioclase, mostly about Ab_2An_1 to Ab_1An_1, are rather abundant, and there are less well-shaped and generally thicker plates of what appears to be sodic orthoclase; these are mostly untwinned. Small grains of magnetite are present, but are not numerous. No olivine grains are to be seen. There is a small amount of clear colorless basis interstitial in patches; some of this is feebly birefringent and some isotropic. It is probably the nephelite indicated by the norm as present or, in part, glass. The microtexture is typically basaltic, and there is no indication of flow.

A chemical analysis gave the results shown below. This and the corresponding norm greatly resemble the analysis and norm of the pahoehoe of San Felix, which has been called nephelite basanite because of its content in olivine and the notable amount of nephelite in the norm. Limburgitic basalt would probably be a more appropriate name for this than the one used above. Because of the small amount of nephelite present and the absence of olivine the San Ambrosio lava may best be called tephritic basalt.

		Norm	
SiO_2	45.41		
Al_2O_3	14.58	Orthoclase	14.46
Fe_2O_3	3.22	Albite	19.39
FeO	8.74	Anorthite	16.96
MgO	4.98	Nephelite	5.40
CaO	9.83	Diopside	20.51
Na_2O	3.53	Olivine	5.24
K_2O	2.39	Magnetite	4.64
H_2O+	0.82	Ilmenite	10.06
H_2O-	0.27	Apatite	2.35
TiO_2	5.30		
P_2O_5	1.00		
MnO	n. d.		
	100.07		

Tephritic basalt, (III).5".".3.4. San Ambrosio Island, South Pacific. Washington, analyst.

In the analysis of the San Ambrosio basalt may be noted the rather high alkalies, especially potash, and the high titanium and phosphorus oxides. Both of these last two peculiarities appear to be characteristic of the more femic lavas (basalt, basanite, etcetera) of the Intro-Pacific volcanoes. In the San Ambrosio rock the abundant titanium is mostly in the augite, as is shown by its peculiar color and the small amount of "ore." The resemblance of this analysis to that of the San Felix pahoehoe indicates the intimate relation of the two volcanic islands.

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PHYSIOGRAPHIC DEVELOPMENT OF THE NORTHERN GREAT PLAINS[1]

BY WILLIAM C. ALDEN

(Presented in abstract before the Society December 27, 1923)

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[1] Manuscript received by the Secretary of the Society April 21, 1924.
Summary read before Washington meeting of Geological Society of America, December 27, 1923.
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Introduction

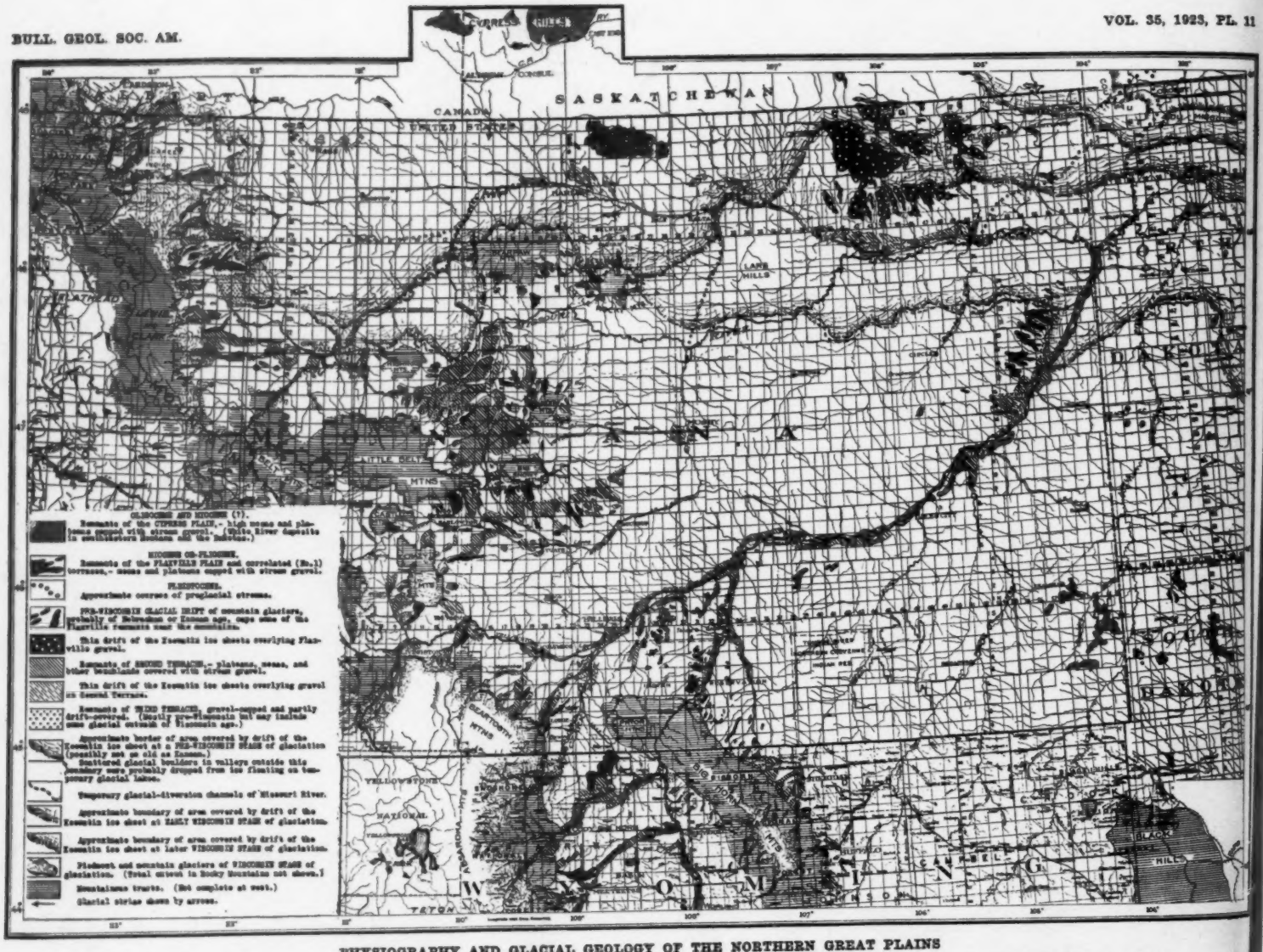
General statement

This paper is a summary of the results of a study, not yet completed, of the Tertiary and Pleistocene gravel terraces and associated glacial deposits and erosional phenomena of the plains of Montana, Big Horn Basin, Wyoming, and adjacent areas. The writer's studies, which have extended over a large part of six field seasons, are in the nature of a rapid reconnaissance of this vast area for the purpose of adding to and correlating data observed by a large number of other geologists who have worked in this region. The deposits mapped and the correlations made are shown on plate 11 as well as can be done on this small scale. It is hoped to present a better map, more detailed descriptions, and discussion of the evidence in an official paper now in preparation. Most of the detailed mapping, where such has been done, is the work of others—that is, men engaged principally in the coal and oil land investigations. The following may be mentioned:

C. Max Bauer, A. L. Beekly, C. F. Bowen, W. R. Calvert, S. H. Cathcart, A. J. Collier, C. E. Dobbin, C. A. Fisher, M. I. Goldman, G. M. Hall, E. T. Hancock, C. J. Hares, F. A. Herald, D. F. Hewett, C. T. Lupton, L. J. Pepperberg, Frank Reeves, R. W. Richards, G. S. Rogers, Carl D. Smith, Eugene Stebinger, R. W. Stone, W. T. Thom, Jr., and L. H. Woolsey.

Earlier work was done by N. H. Darton and W. H. Weed and their assistants in and near the mountains; by R. G. McConnell, E. D. Cope, and L. M. Lambe in the Cypress Hills, Saskatchewan, and by T. C. Chamberlin, R. D. Salisbury, and F. H. H. Calhoun on the glacial drift. Mention should also be made of the work of A. G. Leonard and others in North Dakota. This looks like a formidable array of talent, but it may be stated that in most cases, excepting the latter groups, the studies and mapping of the deposits discussed in this paper were merely incidental to other work in hand and little attention was given to the general relations and real significance of these phenomena. Exceptions to this statement will be evident from the text.

The writer's own work has included parts of the field seasons of 1911, 1912, 1922, and 1923, and the full field seasons of 1916, 1920, and 1921,


SASKATCHEWAN
CANADA
UNITED STATES
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
WYOMING
LITTLE ROCKY MTNS
LITTLE BELT MTNS
BIG HORN MTNS
YELLOWSTONE NATIONAL PARK
BLACK HILLS
PLATEAU
LAKE MILLS
TETON
OLIGOCENE AND MIOCENE (?).
Remnants of the CYPRESS PLAIN,- high mesas and plateaus capped with siliceous gravel. (White River deposits in southwestern Montana and the Dakotas.)
MIOCENE OR PLIOCENE.
Remnants of the FLAXVILLE PLAIN and correlated (No.1) terraces,- mesas and plateaus capped with siliceous gravel.
PLEISTOCENE.
Approximate courses of proglacial streams.
PRE-WISCONSIN GLACIAL DRIFT of mountain glaciers, probably of Nebraskan or Kansan age, caps some of the Flaxville remnants near the mountains.
Thin drift of the Keewatin ice sheets overlying Flaxville gravel.
Remnants of SECOND TERRACE,- plateaus, mesas, and other benchlands covered with siliceous gravel.
Thin drift of the Keewatin ice sheets overlying gravel as Second Terrace.
Remnants of THIRD TERRACE, gravel-capped and partly drift-covered. (Mostly pre-Wisconsin but may include some glacial outwash of Wisconsin age.)
Approximate border of area covered by drift of the Keewatin ice sheet at a PRE-WISCONSIN STAGE of glaciation (possibly not so old as Kansan.)
Scattered glacial boulders in valleys outside this boundary were probably dropped from ice floating on temporary glacial lakes.
Temporary glacial-diversion channels of Missouri River.
Approximate boundary of area covered by drift of the Keewatin ice sheet at EARLY WISCONSIN STAGE of glaciation.
Approximate boundary of area covered by drift of the Keewatin ice sheet at later WISCONSIN STAGE of glaciation.
Piedmont and mountain glaciers of WISCONSIN STAGE of glaciation. (Total extent in Rocky Mountains not shown.)
Mountainous tracts. (Not complete at west.)
Glacial striae shown by arrows.

PHYSIOGRAPHY AND GLACIAL GEOLOGY OF THE NORTHERN GREAT PLAINS

This map was prepared by William C. Alden, using data from field studies by Alden, Stebinger, Calhoun, and many other geologists. Tentative correlations mostly by Alden, 1924. Terraces on Little Missouri River and about Black Hills not shown and elsewhere mapping is not wholly complete.

and has been principally in the nature of a reconnaissance with a view to adding to and correlating the available data and ascertaining their significance.

The area covered embraces most of the plains of Montana east of the mountains, together with some of the western part of North Dakota and adjacent portions of southern Alberta and Saskatchewan, Big Horn Basin, Wyoming, and the environs of Big Horn Mountains. When it is noted that this is equivalent in area to the whole of New York, Pennsylvania, New Jersey, Delaware, and Maryland, and that something like 25,000 miles of traverses were made by the writer with a Ford auto, with observations en route, something of the nature of this study of the region will be appreciated. Indeed, the writer fears he may be laying himself liable to the charge of doing superficial rather than surficial geological work. Such an imputation might possibly be justified were it not for the previous work of the other men cited.

GENERAL CHARACTERISTICS OF THE PLAINS

The Northern Great Plains rise gradually westward from elevations between 1,800 and 2,400 feet above sealevel, on the Couteau du Missouri east of Missouri River, in North Dakota, to elevations of 5,000 to 6,000 feet at the foot of the Rocky Mountains. The front of the Rockies in general rises abruptly from the prairies to elevations of 8,000 to 10,000 feet above tide, and some distance back are peaks rising to heights of 9,000 to 10,000 feet above tide in Glacier National Park, and 11,000 to 12,000 feet above tide and more in the Big Horn Mountains and the rugged region north and east of Yellowstone Park. In this connection attention may be called to the fact, which is probably already familiar to many, that the country east of the mountains, known as the Northern Great Plains, is far from being a smooth, flat surface. It is true that there are considerable smooth, flat tracts and large gently rolling areas, and that as one looks out over the plain from a high point on the mountains the whole vast plain looks as flat as a floor, in contrast with the boldness of the mountain ridges. This impression is, however, due to the fact that the features are much smaller and lower than the mountains, and that the details are lost in the hazy distances. Particularly outside the drift-covered part—that is, in most of the plains region south and west of Missouri River—there is a good deal of very rough country. Not only in the breaks along the Missouri and the Yellowstone is there deep and thorough dissection, in places typical bad lands, but in the larger interstream tracts ridges rise in places 500 to 1,500 feet above the

valley bottoms, often with bold cliffs and picturesque towers and pinnacles, especially where the eminences are capped with sandstones.

Missouri and Yellowstone rivers flow for the most part in rather narrow young valleys bordered by lines of abrupt bluffs 100 to several hundred feet in height. In many places on Missouri River below Great Falls, on the Marias and Teton, the lower Musselshell and Little Missouri, the inner valleys are narrow gorges, approached with difficulty except on the main graded roads.

MOUNTAIN OUTLIERS

There are several small outlying mountain groups which rise above the plains. With these may be grouped the Sweetgrass Hills, three igneous laccolithic buttes near the Canadian line (6,300± feet above tide), of early Tertiary age. The mountains are the Bearpaws, post-Eocene volcanics (6,000 to 7,000 feet above tide); Little Rocky Mountains (6,000 to 6,500 feet above tide), laccoliths of early Tertiary age; Highwood Mountains, volcanics of Tertiary age (7,240 feet); North and South Moccasin Mountains and Judith Mountains, early Tertiary laccoliths (6,000 to 8,600 feet above tide); Big Belts and Little Belts and Big Snowy Mountains, early Tertiary anticlinal uplifts and faulted laccoliths (7,000 to 9,000 feet above tide); Castle and Crazy Mountains, faulted laccoliths and intrusives of Eocene age (8,000 to 11,000 feet). To the south are the Pryor Mountains (nearly 8,800 feet above tide) and Big Horn Mountains, rising over 13,000 feet above tide and separated from the Pryor Mountains by the lower Big Horn Canyon. These are early Tertiary anticlines or uplifts, and farther east are the Black Hills.

ROCKS OF THE PLAINS

The rocks of the plains in Montana and Wyoming are mostly shales and sandstones, ranging in age from early Cretaceous through Eocene. The particular deposits discussed in this paper are mostly nonglacial river gravel, ranging in age from Oligocene through Pleistocene, and glacial drift.

In western North Dakota are several isolated buttes capped with deposits of supposed Oligocene age. One of these, Sentinel Butte, about 10 miles east of the Montana line, rises to 3,430 feet above tide and is the second highest point in North Dakota. It is not certainly known that any Oligocene formations remain on the plains of Montana except in the southeastern corner, where there are remnants of White River deposits. The possibility that there may be other small remnants of Oligocene or Miocene age is discussed below. Not since the deposition

FIGURE 1.—QUARTZITE PEBBLE CONGLOMERATE (OLIGOCENE-MIOCENE) CAPPING CYPRESS HILLS, ALBERTA

Exposure near west end of the plateau.

FIGURE 2.—PEBBLES, MOSTLY QUARTZITE, CAPPING CYPRESS HILLS, ALBERTA

Shows smooth waterworn shapes and sizes up to 8 by 10 by 12 inches.

QUARTZITE PEBBLE CONGLOMERATE AND QUARTZITE PEBBLES

of the Cannonball marine member of the Lance formation, near the end of the Cretaceous or the beginning of Tertiary time, has this region stood so low that marine waters invaded western North Dakota or Montana.

Oligocene and Miocene

Oligocene deposits and the Cypress plain

North of Havre and 40 to 50 miles north of the International Boundary is the plateau known as the Cypress Hills, the highest feature in this part of the plains and a part of the Continental Divide. This plateau, which is nearly 80 miles in length from east to west, lies mostly in southwestern Saskatchewan, but extends westward about 20 miles into southeastern Alberta. Here it terminates as a narrow wedge at "Head of the Mountain," with an elevation of 4,850 feet above tide, or nearly 2,000 feet higher than South Saskatchewan River on the north and Milk River on the south. The flat top is broken into several segments by gaps due to erosion, some of them several miles in width. The eastern segment has a width of nearly 25 miles. The plateau top, where not cut by erosion, is flat as a floor and slopes eastward with an average grade of about 12 or 13 feet per mile. By dint of some muscular assistance the automobile was driven up the steep marginal slope of the western segment, about 1,000 feet above the immediately surrounding plain, and the writer was surprised to find on the top numerous dry land farms with fields of wheat. Part of the top and the northern slope, which are timbered, are embraced in the Dominion Forest Reserve.

In this western part the plateau is capped with a thick deposit of coarse waterworn gravel which is in places cemented to a conglomerate by calcium carbonate (plate 12, figure 1). This is said to overlie unconformably shales and sandstones of Lance and Fort Union age. The gravel contains some sand, but is mostly smoothly rounded pebbles of quartzite and fine-grained siliceous argillite, with some chert and vein quartz ranging in size from a fraction of an inch to cobblestones 8 by 10 by 12 inches in diameter. Many of the pebbles are over 6 inches in diameter (plate 12, figure 2).

McConnell,[2] whose report on this region was published in 1885, states that the conglomerate is about 50 feet thick, and in the eastern part of the hills it is associated with cross-bedded sandstone, sand, clay, and marl, where the thickness of the whole deposit reaches 500 feet. The best exposures are said to be in the sides of Bone Coulée, which is north

[2] R. G. McConnell: On the Cypress Hills, Wood Mountain, and adjacent country Canada Geol. Survey Ann. Rept., vol. 1, new ser., 1886, pp. 1c-78c.

of the village of East End. Here McConnell in 1883, Weston in 1884, 1888, and 1889, and Lambe in 1904, collected vertebrate remains and a few invertebrate fossils. Lambe[3] in his report, published in 1908, makes the following statement:

"Cope,[4] in his memoir of 1891, qualifies McConnell's assignment of the uppermost beds of the Cypress Hills to the Miocene by describing them as of Oligocene or Lower Miocene age. Matthew would accord them a more definite horizon at the bottom of the Oligocene, and has expressed the opinion that they are probably of approximately the same age as the Titanotherium beds at Pipestone Springs, Montana. This opinion appears to be borne out to some extent by the list of species from Pipestone Springs, published by Dr. Matthew in 1903, and the collections from the Cypress Hills, supplemented by the material secured in 1904."

It should be noted in this connection that if these deposits on Cypress Hills are regarded as wholly of Oligocene age, no data are now in hand for distinguishing any others in the region under discussion as strictly of Miocene age.

It seems to the present writer beyond question that the materials capping the Cypress Hills are principally, at least, alluvial deposits formed by a vigorous stream heading in the Rocky Mountains. This is well stated by Mr. Lambe as follows:

"That the Cypress Hills Oligocene deposits were the result of rapidly flowing water from the west is evident. The thick basal beds of rounded pebbles represent the work of a strong transporting force, such as would be supplied by a turbulent stream of considerable size carrying eastward material from the Rocky Mountains. The sands show false bedding as a result of varying currents. With the accumulation of material eastward, and a consequent reduction of the transporting force, beds of finer material were deposited at a higher level, and probably on extensive areas of overflow."

The pebbles examined by the present writer are mostly well rounded and have remarkably smooth and even polished surfaces, many of which are covered with percussion marks such as are produced by stones striking sharply against one another in a strong current. The source of the material is clearly the Rocky Mountains, 150 to 200 miles west of the head of the plateau. In view of this distance, the size of the larger stones

[3] L. M. Lambe: A new species of Hyracodon (*H. priscidens*) from the Oligocene of the Cypress Hills, Assiniboia: Canada Roy. Soc. Proc. and Trans., 2d ser., vol. 11, sec. 4, 1906, pp. 37-42; Fossil horses of the Oligocene of the Cypress Hills; Idem, pp. 43-52; Vertebrata of the Oligocene of the Cypress Hills, Saskatchewan: Canada Geol. Survey Contr. Paleontology, vol. 3, 1908, pt. 4.

[4] E. D. Cope: The Vertebrata of the Swift Current Creek region of the Cypress Hills: Canada Geol. Survey Ann. Rept., vol. 1, new ser., pp. 79c-85c; The species from the Oligocene or lower Miocene beds of the Cypress Hills: Canada Geol. Survey Contr. Canadian Paleontology, 1891.

is remarkable. Of those shown in plate 12, figure 2, the largest have dimensions of 8 by 10 by 12 inches. None of the stones examined shows any evidence of transportation by glacier ice. McConnell[5] has pointed out that:

> "The area now covered by the Cypress Hills has been changed from a depression in Miocene [Oligocene] times into the highest plateau on the plains, which is its present position, entirely by the arrest of denudation over its surface by the hard conglomerate beds which cover it, whilst the surrounding country, destitute of such protection, has been gradually lowered; and so affords an index of the amount of material removed from the neighboring plains in the age intervening between the deposition of the Miocene [Oligocene] and the Glacial period. The conglomerate capping now overlooks, from a height of fully 2,000 feet, the lowest part of the plain stretching from the western base of the plateau to the mountains."

Going upstream, the bed of the ancient river must have risen rapidly "in order," as McConnell states, "to induce a current powerful enough to urge forward such immense quantities of pebbles and boulders 200 miles from their nearest source. For this work an easterly slope of at least 15 feet per mile would be required." This is about the present gradient of the base of the alluvial deposit capping the plateau. The slope of the remarkably flat surface of the deposit on the western segment of the plateau is now about 12 or 13 feet per mile.

In order to get some conception of the probable relations of the plains and mountains in Oligocene and Miocene time, a stream gradient may be projected westward from the head of the Cypress Hills (4,843 feet above tide) 155 miles, to the Rocky Mountains in the vicinity of the International Boundary, somewhat as follows: 10 feet per mile for 100 miles, 20 feet per mile for 20 miles, 40 feet per mile for 20 miles, 75 feet per mile for 10 miles, and 100 feet per mile for the last 5 miles near the mountains. Continued west at the latter grade, it would overtop all but the highest mountain crests in Glacier Park. Here no summit or subsummit plateau remains, unless it be represented by such tops as that of East Flattop Mountain. The grade postulated is, in general, very close to that observed on some of the lower terraces.[6]

Just what were the actual altitudes of the Rocky Mountains is not

[5] Op. cit., pp. 69-c, 70-c.

[6] In the projection of stream gradients and the attempted correlations on the basis of stream gradients, relative elevations, and other physiographic relations in this study, there is no pretense of accuracy of detail; approximation is the best that can be hoped for, and there is necessarily considerable room for differences of opinion as to some conclusions. Barometric readings have generally been taken where published data on elevations were not available, and projected gradients have been assumed corresponding with those which are now found on benches and terraces in similar situations in this region, with some allowance for local modifying factors.

known, but the crest of the range in the Glacier Park region may have been within 3,000 feet of the present height—that is, possibly 6,000 to 7,000 feet above tide. Farther south the mountains may have been higher. So far as known to the writer, there is no evidence that the mountains have risen less than the bordering plains since Oligocene time. Probably the reverse is the case. Assuming the relative elevations of the Cypress Hills and the Front Range of the Rockies near the International Boundary to have been not greatly different from what they are now, the projected gradient may show approximately the horizon at which the gravel-bearing Oligocene streams issued from the mountains. This projected grade reaches Chief Mountain about 200 feet below the top, or 8,850 feet above the sea. It is about 3,100 feet higher than Saint Mary River (which is 4,200 feet above tide) at the Boundary, 3,150 feet higher than the gravel-capped outlier east of Chief Mountain, known as Kennedy Ridge (5,000 feet above tide), and fully 5,000 feet higher than Belly River. This horizon would be far above the plane of the Lewis overthrust, and farther south would overtop the higher part of the smoothly worn crest of East Flattop Mountain (7,200 to 8,300 feet above tide) near lower Saint Mary lakes. It would be near the top of Rising Wolf Mountain, north of Two Medicine lakes, and would be fully 2,000 feet higher than the top of the ridge north of Lower Two Medicine Lake, which is correlated with the Flaxville Plain and which is capped with the ancient glacial deposit described below, page 393.

It is notable that nowhere back in the mountains of the Glacier Park region are there now any land forms to be correlated with such a gradient, unless they be the peaks of the mountains themselves, and even these have probably been greatly modified in subsequent ages.

McConnell evidently regarded the gravel deposits on the Cypress Hills as originally distributed along a valley bordered by higher lands. This may really have been the case, inasmuch as remnants of deposits of similar age, character, and topographic position are not now found for long distances either to the north or south.

However, the wide distribution of similar later gravels suggests that the Oligocene and Miocene (?) fluvial deposits may have been widely spread over a broad, gently sloping, nearly flat plain composed of coalescing alluvial fans heading at those points where the streams debouched from the mountain gorges. For this plain, as represented by correlated terrace remnants, the name Cypress Plain—that is, the plain of the top of the Cypress Hills—is proposed.

That the projected gradient of the Oligocene and Miocene streams is not too high seems clear from a consideration of the gradients of the

lower and younger terraces and benchlands and the present streams. Moreover, this projected grade includes the effects of several subsequent differential uplifts. There is a boulder bed on Saint Mary River a few miles north of the Boundary Line, where there are many boulders 1 to 2 feet in diameter. They are, however, almost entirely confined to the inner side of the curved bar, where the flood-water current was strongest, and are progressively smaller toward the outside of the bar. They are also in a rather narrow channel and within 15 miles of the mountain front, where the stream has a grade of 30 to 40 feet per mile. Moreover, it is not certain that the larger stones have been transported even this far by the stream, inasmuch as the adjacent hills are strewn with bouldery glacial drift, from which these boulders may have been let down by erosion.

Along the bed and banks of Boulder River, tributary to the Yellowstone, at Big Timber, east of Livingston, there are many well rounded boulders 2 to 3 feet in diameter. These have clearly been brought by the present or earlier stages of the stream at least the distance which they now are from the terminal moraine of the former mountain glacier, 11 miles to the south. The stream here emerges from a valley one-half to one mile wide, with a grade in the last 4 miles ranging from 65 feet per mile down to 20 feet per mile. Some of this transportation was probably accomplished by flood waters from the melting glaciers of later Pleistocene time. Considering all the factors, it seems probable that the projected gradient of the Oligocene stream which deposited the gravel on Cypress Hills is not too high, and that this and contemporaneous streams were debouching on to the plains at horizons now well up toward the top of the mountain fronts.

As on the Cypress Hills, so in North Dakota, the small and isolated remnants of supposed Oligocene age cap the highest buttes and may represent a continuous plain. There they are principally clays and marls, fresh-water limestone, and some pebbly sandstones, evidently lake and stream deposits. In some of these Earl Douglas[7] found fossils of White River (Oligocene) age. Those on Sentinel Butte near the Montana line, at 3,430 feet above tide, are said to contain remains of fresh-water fishes. A gradient from the top of Sentinel Butte to White River beds, on the northern Black Hills, at 5,300 feet above tide, would average about 12 feet per mile.

No deposits of Oligocene age are certainly known to occur on the plains

[7] Earl Douglas: Annals of Carnegie Mus., vol. v, 1909, pp. 281-288.
See, also, A. G. Leonard: Geology of North Dakota. Jour. Geol., vol. 27, 1919, pp. 20-21.

east of the Rocky Mountains in Montana, except in the southeast corner of the State. All other traces appear to have been removed by erosion, unless it be that Oligocene or Miocene river deposits are represented by the coarse gravel noted below. Such gravel was found by the present writer, in 1922, in the northeastern part of Prairie County, capping small remnants of a high plain on the crest of the divide about 25 miles northwest of Terry. One of these remnants forms the top of Big Sheep Mountain, about 1,400 feet above the level of Yellowstone River and 3,600 feet (barometric) above sealevel. So, also, the coarse gravel found by Rogers[8] on the flat top of Pine Ridge of Big Horn River in Big Horn County, Montana, now 1,100 feet above Yellowstone River and about 4,000 feet above tide, and by Hancock[9] south and southeast of Huntley, on the highest ridges, 1,000 feet or more above the Yellowstone, at 3,900 to 4,200 feet above tide, may, perhaps, be Oligocene or Miocene.

On the basis of the character and topographic relations of the remnants of deposits described above, and the analogous relations of the Oligocene (White River beds) in South Dakota, Wyoming, Colorado, and Nebraska, and judging from conditions which developed later and which are described elsewhere in this paper, there appears to be justification for drawing a picture of Montana and adjacent regions in Oligocene and Miocene time as follows:

At the west the Rocky Mountains had by Oligocene time risen to a considerable height. Just what was the actual altitude above sealevel is not known, but the crest of the range in the Glacier Park region may have been within 3,000 or 4,000 feet of the present height, possibly 6,000 to 7,000 feet above tide. Vigorous erosion had stripped off whatever covering of Mesozoic and Paleozoic rocks overlaid the Algonkian limestone, quartzites, and argillites concordantly with the rise of the mountains. The Great Plains had risen somewhat at the east and more at the west, so that the great fresh-water lakes of Eocene time were drained; the gradients of streams were increased and vast quantities of coarse gravel and cobblestones, derived very largely from the Algonkian rocks, were swept eastward across the plains.

The eastern part of the Cypress Hills Plateau is about 850 miles from the nearest point on Hudson Bay. If it be supposed that the elevation of the Cypress Hills has increased as much as 2,000 feet since Oligocene time, its altitude at that time must have been about 2,800 feet above tide, where now is the "Head of the Mountain," and 1,700 feet at the

[8] G. S. Rogers: Geology and coal resources of the area southwest of Custer, Yellowstone, and Big Horn counties, Montana. U. S. Geol. Survey Bull. 541, 1914, p. 317.

[9] E. T. Hancock: Geology and oil prospects of the Huntley field, Montana. U. S. Geol. Survey Bull. 711, 1919, pp. 128-129.

east end, which would leave a gradient of about 2 feet per mile, measured on an airline (850 miles) to the nearest point on the present shore of Hudson Bay—that is, about the same as the present gradient of South Saskatchewan River. That stream in the part of its course north of the Cypress Hills descends from an elevation of 2,142 feet above tide at Medicine Hat to about 1,758 feet north of the east end of Cypress Hills, and its waters reach sealevel via Lake Winnepeg and Nelson River, at York Factory, the nearest point on Hudson Bay.

On the basis of the stream gradient assumed west of the Cypress Hills tract, the streams would be issuing from the mountain valleys on to the plains at a horizon not far from that now represented by the top of Chief Mountain and by the upper crest of East Flattop Mountain (now about 8,300 to 8,850 feet above tide, then perhaps 4,500 to 5,000 feet above tide, or about the altitude at which the present streams issue). The mountains probably had a worn-down aspect by the close of Miocene time, lacking the bold, high cliffs now seen, but doubtless peaks still rose 2,000 to 3,000 feet above the bordering plains.

There is reason to believe that in Tertiary time all the drainage of Montana east of the mountains was northeastward to the ocean or Hudson Bay rather than, as now, mostly to the Gulf of Mexico, more than twice as far away. One principal member of the Oligocene and Miocene drainage system was perhaps along the tract which is now the top of the Cypress Hills Plateau. Another of similar grade and proportions may have been the forerunner of the Upper Missouri and Milk rivers, and still others may have been the precursors of the Yellowstone and Big Horn rivers. All these probably laid down thick beds of coarse gravel, sand, and clay, and, if conditions were analogous to those east and south of the Black Hills, the heavily loaded streams frequently filled their shallow courses with debris and shifted from side to side until, near the mountains, they produced coalescing alluvial fans of vast extent, which resulted in a remarkably flat and gently sloping plain, similar to that of eastern Colorado, Nebraska, and Kansas.

OLIGOCENE OR MIOCENE PENEPLAIN

There are no remnants of an Oligocene or Miocene peneplain in the Glacier Park region.

South of Glacier Park the mountains are less well known to the writer, but topographic maps give little indication of a peneplain. Some of the smooth parks on the Little Belt and Big Snowy Mountains suggest peneplanation, but they may be due, in part at least, to the nearly flat-lying positions of underlying rocks. In many places the condition was doubt-

less much the same as shown in a view taken by Darton on the southern part of Big Horn Mountains, 8,000 to 9,000 feet above tide (plate 13). Here the subsummit plain is underlain by gravel of supposed Oligocene or Miocene age and in the background are mountain peaks rising 2,000 to 4,000 feet higher.[10] Weed[11] states that at the close of the Eocene (then regarded as including Oligocene time) the entire area of the Little Belt Quadrangle, including the Little Belt, Castle, and Crazy Mountains, was reduced to a gently hilly country bordered by a broad, level plain.

On the mountains north and northeast of Yellowstone Park there are remarkably smooth uplands between the profound gorges. These range in altitude between 9,000 and 11,000 feet above tide and are evidently dissevered remnants of one continuous peneplain. Several parts are designated on maps, as Beartooth, Fishtail, Lake, and East and West Boulder plateaus. They are mostly underlain by Archean granite, gneiss, and schist, and they stand high above the beveled edges of the Paleozoic, Mesozoic, and Eocene beds upturned along the mountain fronts. Above them rise peaks of the Granite and Snowy ranges to a maximum height of more than 12,000 feet above tide. These plateaus may really be remnants of an Oligocene or Miocene peneplain which has been uplifted 4,000 to 5,000 feet since the time of its development.[12] It now stands at that height above the streams issuing from the mouths of the profound canyons by which it is dissected. The mountain front is a bold "fault-line" scarp uncovered by erosion. To get to the point on the edge of the plateau, where the view shown in plate 14 was taken, the writer climbed 4,500 feet from the plain north of the mouth of Clark Fork Canyon.

POSSIBLE OLIGOCENE OR MIOCENE REMNANTS

Reference has been made to the high-level gravel on Big Sheep Mountain northwest of Terry. Unfortunately no fossils were found in this. It is, however, several hundred feet higher than would be expected if a remnant of the younger set of terraces and a gradient of but 2 or 3 feet per mile would connect it with the supposed White River beds on Sentinel Butte, about 90 miles to the eastward. It is about 1,400 feet above the Yellowstone at Terry and may be Oligocene or Miocene in age. The gravel caps the divide on the highest land in this part of the State and

[10] N. H. Darton: Geology of Big Horn Mountains, Wyoming. U. S. Geol. Survey Prof. Paper 51, 1906, pp. 67-68.

[11] W. H. Weed: U. S. Geol. Survey Geol. Atlas, Little Belt Mountains folio (no. 7), 1899, p. 7.

[12] See Arthur Bevan: Summary of the geology of the Beartooth Mountains. Jour. Geol., vol. 31, 1923, pp. 445, 463-464.

Considering the relations discussed later in the present paper, it does not seem to me that the subsummit peneplain can be younger than Miocene.—W. C. A.

VIEW ON BIG HORN MOUNTAINS, WYOMING

High plain of supposed Tertiary deposits, a part of the subsummit plateau. Near Canyon Creek, 10 miles west of Hazleton, Wyoming. Altitude, 9,000 feet above tide. Peaks of the central crest in background 11,000 to 13,165 feet above tide. Photograph by N. H. Darton.

SUBSUMMIT PLATEAU AND EAST FRONT OF BEARTOOTH MOUNTAINS, WYOMING, NORTH OF CLARK FORK OF YELLOWSTONE RIVER

Plateau on granite and gneiss 9,000 to 10,000 feet above tide, plains at right 4,500 to 5,000 feet above tide. View north along Beartooth fault.

is clearly a river deposit. The pebbles are smoothly rounded and range from fine to cobblestones 6 to 10 inches in diameter. They consist of various porphyries, some granite, quartzite, quartz, chert, and silicified wood. Most, if not all, are from the mountains 300 miles to the west.

The great height of the gravel caps on Pine and other ridges between Yellowstone River and the Big Horn east of Billings, as described by Rogers and Hancock, gives rise to the suggestion that these also may be remnants of an Oligocene or a Miocene plain. These are about 4,000 feet above sealevel and 1,000 to 1,100 feet above Yellowstone River in a part of the course where the main early Pleistocene terrace is only 100 to 200 feet above the stream. One of these high remnants is crossed by the Custer Battlefield Highway. It is most interesting to see the dry-land farms on this old river terrace so high above the present stream. There are 30 or 40 feet of coarse gravel underlying the thin loamy soil. The gravel is in places cemented to conglomerate and there is some sandstone. The smoothly worn pebbles are like those on Big Sheep Mountain. No fossils indicative of the age of the gravel have been found.

W. T. Thom, Jr., found remnants of a similar plain farther south, on both sides of Big Horn River, at elevations of 4,200 to 5,300 feet above tide, which should perhaps be correlated with these, though they are grouped with the next younger set on the map (plate 11). Projected southward with a normal increase in gradient, the upper plain would reach the Pryor and Big Horn Mountains high up on the flanks.

The cap of andesitic gravel on Tatman Mountain, about 5,800 feet above tide, in the middle of the Big Horn Basin, is also a probable correlative. This so-called "mountain" is an erosional remnant, or butte, composed of nearly flat-lying Tertiary shales and sandstones, which rises 1,200 or 1,300 feet above the bottom lands of Greybull River on the north. The gravel capping the top of the mountain was regarded, on the basis of its stratigraphic position, as possibly Oligocene by Sinclair and Granger.[13] The fact that the gravel consists principally of andesite pebbles may, however, indicate that the gravel is not older than Miocene, for the andesitic rocks composing the Absaroka Mountains to the west, from which the pebbles were doubtless derived, are regarded as of Miocene age. No quartzites are now known to be exposed in these mountains where they would be likely to contribute to the gravel on Tatman Mountain, but such may, perhaps, lie deeply buried beneath the Tertiary volcanics. Some quartzite pebbles are stated to be mingled with the andesitic pebbles on Tatman Mountain. These quartzite pebbles may

[13] W. J. Sinclair and Walter Granger: Eocene and Oligocene of the Wind River and Big Horn basins. Bull. Am. Mus. Nat. History, vol. 30, 1911, pp. 87-88, 111.

YELLOWSTONE RIVER
Plateau on granite and gneiss 9,000 to 10,000 feet above tide, plains at right 4,500 to 5,000 feet above tide. View north along Beartooth fault.

have been derived from the Wasatch conglomerate, which outcrops between Tatman Mountain and the mountains to the west. This conglomerate consists principally of such pebbles where seen by the present writer, near Meeteetse, but no pebbles of volcanic rock were noted therein.

A stream gradient projected eastward 30 to 35 miles from the edge of the smoothly worn top of Carter Mountains, a spur of the Absarokas (10,000 feet above tide), would coincide with the gravelly cap of Tatman Mountain, if an initial slope of 250 feet per mile decreased gradually to a fall of about 40 feet per mile. Judging from the grades to the lower terraces in this basin, even this is not an abnormally high gradient, inasmuch as it includes the effects of post-Miocene differential elevation. Swinging to the northward as it joined Big Horn River, the drainage which deposited this gravel had to cross Sheep and Little Sheep Mountain anticlines and the great Pryor-Big Horn Mountain uplift. The heavy limestones and sandstones in these undoubtedly retarded erosion, and as a consequence it is found that a stream with a gradient of but 10 feet per mile, projected northward for the next 80 miles from the gravel on top of Tatman Mountain, would issue at 5,000 feet above tide from the sag in the bottom of which is cut the lower canyon of Big Horn River. This is not far from the altitude of Pryor Mountain gap (5,260 feet above tide) to the west and of the highest of the gravel remnants which Thom found near the north flank of Pryor Mountains and the northern part of the northeast flank of Big Horn Mountains, in Montana (see page 397). A grade of 30 feet per mile for the succeeding 35 miles would connect with the gravel-capped top of Pine Ridge between the converging Big Horn and Yellowstone valleys.

The highest known remnants of the gravel-covered terraces along Yellowstone are those cited above as on the crests of the ridges east and west of Pryor Creek, east of Billings, about 4,000 feet above tide. The more westerly one is about 65 miles northeast of the edge of subsummit Beartooth Plateau and about 1,000 feet above Yellowstone River. To connect the plateau surface with this terrace remnant would require a high stream gradient. It would extend the marginal slope of the plateau, which is fairly steep near the edge, outward some distance over the plains, and the grade would decrease at a rate something like the following:

	Feet
5 miles at 400 feet per mile = ...	2,000
5 miles at 200 feet per mile = ...	1,000
10 miles at 100 feet per mile = ...	1,000
20 miles at 50 feet per mile = ...	1,000
25 miles at 25 feet per mile = ...	625
Total fall (9,625 feet above tide to 4,000 feet above tide)	5,625

This gradient is high as compared with that observed on the lower terraces of the same region, yet only that of the first few miles seems at all excessive. Perhaps so steep a grade near the mountain front might be accounted for as the result of subsequent differential movement on the Beartooth fault in addition to general easterly tilting. Between 10 and 15 miles from the edge of the plateau, however, this grade would have declined to 100 feet per mile and would be only about 1,200 or 1,300 feet above the highest of the gravel-capped terraces now preserved in the region of Red Lodge.

As stated above, taken in connection with the other phenomena of the region described below, it seems to the writer unlikely that the Beartooth subsummit plateau is younger than Miocene, even if it is not so old as Oligocene. It resulted from long-continued erosion following the Heart Mountain overthrust, but whether or not the development of this plateau occurred prior or subsequent to the extrusion of the volcanic breccias of the Absaroka Range, in upper Miocene time, or whether or not the volcanics extended northeastward over this plateau is not known. If the volcanics did so extend, the northeasterly flowing streams which now deeply dissect the plateau may have originated on the slopes of the old volcano, the remnant of the filling of whose throat constitutes Crandall Stock, a part of Hurricane Mesa[14] south of Clark Fork. There is considerable volcanic material in the gravel capping the high ridges east of Billings, together with granitics, purplish red and yellow quartzites, quartz, agate, opal, chalcedony, and silicified wood. Some of this material, however, probably came down the Yellowstone from farther west.

It is possible that some of these high-level gravels may have been deposited by Clark Fork when it was flowing in a more easterly course than now and traversing the gap at the west end of Pryor Mountains formerly traversed by the Chicago, Burlington and Quincy Railway and which is about 5,260 feet above tide. This gap is about 45 miles northeast of that part of the edge of the plateau near Clark Fork Canyon. In this distance a stream on a gradient similar to that postulated above would be flowing at about the level of this pass, and streams west of Pryor Mountains would be at levels higher than the tops of any of the ridges which now border the valley of Clark Fork on the east.

No features of the plains of Montana or northern Wyoming, excepting the Sweetgrass Hills and outlying mountain groups, rise above the projection of this supposed Oligocene and Miocene Cypress Plain, unless it be the so-called Bull Mountains, between the Yellowstone and Mussel-

[14] J. P. Iddings et al.: Geology of Yellowstone National Park. U. S. Geol. Survey Mon. 32, pt. ii, 1899. See also U. S. Geol. Survey Geol. Atlas, Absaroka folio (no. 52).

shell, and the so-called Wolf and Rosebud Mountains, and similar ridges of Eocene rocks east of Little Horn River.

Miocene or Pliocene

Flaxville plain, or number 1 bench

Since Oligocene time the Northern Great Plains have evidently been in process of degradation. This process appears to have been characterized by a succession of differential uplifts alternating with long periods of still-stand. During each of the uplifts gradients were steepened and the streams deepened their valleys 100 to several hundred feet and the bordering terraces were dissected. During the periods of still-stand both main and tributary streams meandered widely, slopes receded, and broad, flat valley plains were developed at successively lower levels. The details of the process of planation need not be considered here. On these valley plains were spread vast amounts of coarse waterworn gravel in part let down by erosion from older pebbly deposits on higher plains and in part derived directly from canyon-cutting in the mountains. The evidence of this history is found in widely scattered gravel-covered terraces and benchlands. It may be noted in passing that there is a vast amount of this gravel suitable for road metal and concrete work.

The term *bench* or *benchland* is one generally used in this region and perhaps more loosely than it is used in this paper. It is here applied only to those nearly flat features which are clearly remnants of ancient river plains and which are not simply due to the stripping of softer shales from harder flat-lying sandstone. Most of these benches bevel indiscriminately the upturned edges of shales and sandstones, and most of them are thickly covered with coarse gravel below thin loamy soils. In the field the names *bench* and *terrace* have been used more or less indiscriminately and interchangeably for the tops of gravel-capped plateaus or mesas which, like the Cypress Hills, stand well above their immediate surroundings, and also for typical terraces which are bordered on the one hand by lower lands and on the other by slopes rising to higher lands. These features merge into one another. The plateaus and mesas are in many places, especially near the mountains, erosional remnants of great alluvial fans. Some of these may have extended far out over the Northern Great Plains and may have coalesced into continuous smooth, flat tracts of vast extent, such as are preserved in the High Plains farther south. In other cases they narrowed between somewhat higher lands on either side and extended down the valleys as broad, smooth, gravelly bottom lands. These are now deeply dissected terraces.

FIGURE 1.—FLAXVILLE PLAIN OF NORTHEASTERN MONTANA

View west of Scobey, Montana. Photograph by A. J. Collier.

FIGURE 2.—GRAVEL UNDERLYING THE FLAXVILLE PLAIN (MIOCENE OR PLIOCENE), NEAR WEST FORK, MONTANA

Photograph by A. J. Collier.

FLAXVILLE PLAIN AND UNDERLYING GRAVEL

There are three main sets of benches and terraces below the horizon of the Cypress Plain (Oligocene and Miocene (?)) in the region under discussion, and for convenience of reference these are in places designated number 1, number 2, and number 3, in the order of their development, from earliest and highest to latest and lowest—that is, number 1 is the first set below the number 0 (Oligocene), or Cypress Plain. There are in places some intermediate benches and terraces, but in the main these may be grouped in three sets. They serve as datum planes by which the various physiographic features may be correlated. The distribution and tentative correlation of the known remnants of these benches or terraces is shown on the map (plate 11). The intervening areas are mostly gently rolling indefinite tracts and in part very hilly, with badlands in places.

The largest remnants of the Number 1 set of terraces and benches were mapped by Collier and Thom in 1915 and 1916 and described under the name Flaxville,[15] so that the names *Flaxville Plain, Flaxville terraces,* and *Flaxville gravel* are convenient for use. These cover about 1,800 square miles in the northeastern part of Montana, in the northern parts of Blaine, Phillips, Valley, Roosevelt, Daniels, and Sheridan counties (plate 11). The more easterly tracts range in elevation from 2,500 to 3,000 feet above tide, and the tract north of Harlem, in Phillips and Blaine counties, is 3,000 to 3,200 feet above sealevel—that is, they are 700 to 1,000 feet or more lower than the eastern part of the Cypress Hills Plateau to the north. This depth of downcutting gives some indication of the amount of uplift and northeasterly tilting which preceded the development of the Flaxville Plain. West of the longitude of Harlem and Little Rocky Mountains, which is about 109 degrees west, the uplift appears to have been 1,500 feet or more, and possibly reached 2,000 or even 3,000 feet in the Rocky Mountains. It seems fairly certain that it reached 3,000 feet in the Beartooth Range northeast of Yellowstone Park.

Beneath the thin loamy soil which covers the smooth, flat tracts of the Flaxville Plain (plate 15, figure 1) and overlying the eroded surface of Bearpaw and Lance shales and sandstones, in the tract north of Harlem, are 40 to 70 feet of coarse waterworn gravel like that on the Cypress Hills. In the eastern tract (there overlying also the Fort Union) the deposit consists of similar gravel (plate 15, figure 2), together with marl, sandstone, and volcanic ash, the whole varying in thickness from a few

[15] A. J. Collier and W. T. Thom, Jr.: The Flaxville gravel and its relation to other gravels of the Northern Great Plains. U. S. Geol. Survey Prof. Paper 108, 1918.
A. J. Collier: Geology of northeastern Montana. U. S. Geol. Survey Prof. Paper 120, 1918, p. 35.

feet to nearly 100 feet. Some of this material is cemented by calcium carbonate. This Flaxville Plain comprises the first main set of benches and terraces below the Cypress Plain. From the Flaxville gravel Collier and Thom collected fossils which were identified by Doctor Gidley as remains of various forms of the three-toed horse, rhinoceros, oreodont, camel, saber-tooth tiger, a doglike animal, and fish. Concerning these Doctor Gidley made the following statement:

> "None of the material is sufficiently good or complete to make positive specific determinations, and it is therefore of no value as indicating horizon, except in a broad way. With the exception of the specimen reported as Pleistocene, all the material appears to belong to the upper Miocene. It can be stated positively, I think, that, with the exception noted, the beds from which these fragments were collected can not be older than Miocene or younger than lower Pliocene."

The fossil reported as Pleistocene is a Camelops tooth. Apparently, taking everything into consideration, there is some ground for regarding fluvial deposition as having continued on this plain into Pliocene, if not also early Pleistocene, time.

BASIS OF CORRELATION OF REMNANTS OF THE FLAXVILLE PLAIN

Unfortunately, with one exception, no fossils have been found on any other remnants of this or the lower and younger sets of benches. The correlations which are attempted in this paper are based almost wholly on the physiographic relations and the relations to the glacial drift. The map (plate 11) shows the distribution of what appear to be remnants of the Flaxville Plain, or Number 1 Bench, throughout the plains of Montana and northern Wyoming. It will be noted that there is a great interval between the well preserved bench north of Harlem and the remnants bordering the Rocky Mountains near and south of Glacier National Park. For 180 miles or more no feature of the land excepting Bearpaw Mountains and Sweetgrass Hills now rises to the horizon of the Flaxville Plain. Neither have any remnants of the second bench been found. In this interval the land has been subsequently degraded to an undulating plain at lower levels. The valley now occupied by Milk River and, below Nashua, by Missouri River was occupied by Upper Missouri River before its diversion by the Keewatin ice-sheet. Along this valley there are two lower terraces or benches. The higher of these two terraces—that is, Number 2 Bench—consists of all that is left of the bottom of a well-marked broad valley about 600 feet below the horizon of the Flaxville Plain. This is greatly dissected, and through considerable intervals no traces remain. This smooth, gently sloping bench has in places a width

of 5 or 6 miles. Back of it a steeper slope rises to the Flaxville Plain, and on the lower side it extends to the crest of the steep bluffs which form the sides of the inner valley, which is itself about 3 miles in width. The third terrace is confined to this inner valley.

The development of three similar sets of benches and terraces throughout this region is regarded as significant and as a possible basis of correlation. Thus three sets are remarkably well developed on Yellowstone River, in the Glendive Quadrangle, at similar altitudes and at heights above the stream similar to those on Missouri River, and they are correspondingly dissected.

It seems to the writer, therefore, that the three sets of benches and terraces on the two converging streams belonging to the same river system were severally contemporaneous in their development, and that the highest, or Number 1 Bench of the Glendive Quadrangle, corresponds to the Flaxville Plain in age. These dissected benches are the remnants of an ancient valley floor 20 miles or more in width. From an old worn-down divide the smooth tablelands slope gently to the tops of abrupt dissected slopes at elevations 700 to 800 feet above Yellowstone River. For 150 miles above Glendive there are no known remnants of this number 1, or Flaxville, terrace, unless it be those found by Rogers on Little Sheep Mountain northwest of Terry. As shown on the map (plate 11), what appears to be the second terrace can, however, be traced almost all the way to the mountains, though with numerous, but much shorter, intervals where it has been cut away. Similarly, Number 2 Terrace can be correlated fairly well northward along the mountain fronts and across the upper Musselshell Valley and Judith River Basin. Midway between Judith Basin and the Flaxville Plain north of Harlem are the corresponding gravel terraces about Bearpaw and Little Rocky Mountains. There are, therefore, two fairly good lines of correlation from the typical Flaxville tracts westward to the region of the Missouri at Great Falls and thence west up Sun River Valley and northward bordering the mountain fronts to the region of Glacier National Park. At intervals throughout the great extent of hundreds of miles isolated remnants of a higher set of gravel-capped benches (plate 19, figure 1) are found standing well above the plain of the second set, and these higher ones are, in consequence, regarded as the correlatives of the Flaxville Plain. With these is correlated Hewett's[16] "Rim terrace" on Greybull River, in Big Horn Basin, Wyoming.

[16] D. F. Hewett: Geology, coal and oil resources of Oregon Basin, Meeteetse and Grass Creek Basin quadrangles, Wyoming. U. S. Geol. Survey Bull., in preparation.
See Meeteetse Rim on Meeteetse and Oregon Basin topographic maps.

EROSIONAL FEATURES CORRELATED WITH THE FLAXVILLE PLAIN

Sun River Canyon.—There are certain rather striking erosional features which are probably to be correlated with the development of the Flaxville Plain. Plate 16, figure 1, is a view looking west up Sun River at the south line of Teton County, Montana, west of Great Falls, to the mouth of the canyon from which the stream issues onto the plains. This shows a gap four miles wide in the mountain front. The bottom of the gap is at the top of a great wall of Mississippian limestone upthrust in the mountain front. From the high-level valley, of which this broad gap is a transverse section, the river in late Tertiary time flowed out onto the Flaxville piedmont plain. Twelve miles eastward, and directly in front of this gap, is the head of a large gravel-capped remnant of the Flaxville Plain more than 800 feet above the present bed of Sun River. As noted below, it is probable the first of the Sun River glaciers also issued from this gap and spread out on that part of the ancient piedmont which is now cut away. Before the Sun River Glacier of the Wisconsin stage advanced, the stream had cut a great notch, nearly 1,000 feet deep, through the limestone wall beneath the four-mile sag (plate 16, figure 2). In the bottom of this great notch the stream in post-Wisconsin time cut the narrow gorge, about 180 feet deep, which is now blocked by the irrigation dam.

Clark Fork Canyon.—Corresponding features are found in the canyon of Clark Fork of Yellowstone River in Park County, Wyoming. Plate 14 shows the edge of the subsummit plateau (Oligocene or Miocene?) a few miles north of the Clark Fork Canyon. This edge is 4,500 feet above the plains adjacent to the mountain front.

After tramping 5 or 6 miles up the Clark Fork Canyon and climbing 1,300 feet up a steep zigzag trail to a bench at the top of the canyon wall, on looking westward, the writer found himself in a broad high-level valley (plate 17) 2,000 to 3,000 feet below the subsummit plateau on the north. This broad valley heads far to the northwest in the vicinity of Cooke, Montana, which is near the northeast corner of Yellowstone Park. The stream, when flowing in this valley in late Tertiary time, issued from the mountains at a level about 1,000 feet higher than the present stream bed and flowed across a piedmont plain which was a part of, or correlated with, the Flaxville Plain. Eighteen miles east of the canyon mouth an extensive remnant of this plain is Polecat Bench, 1,000 feet higher than Clark Fork now flows at the Montana-Wyoming State line. Here, also, it may be that immediately following the uplift at the close of the Tertiary the first Clark Fork glacier issued from this broad high-level valley onto that part of the Flaxville piedmont plain which

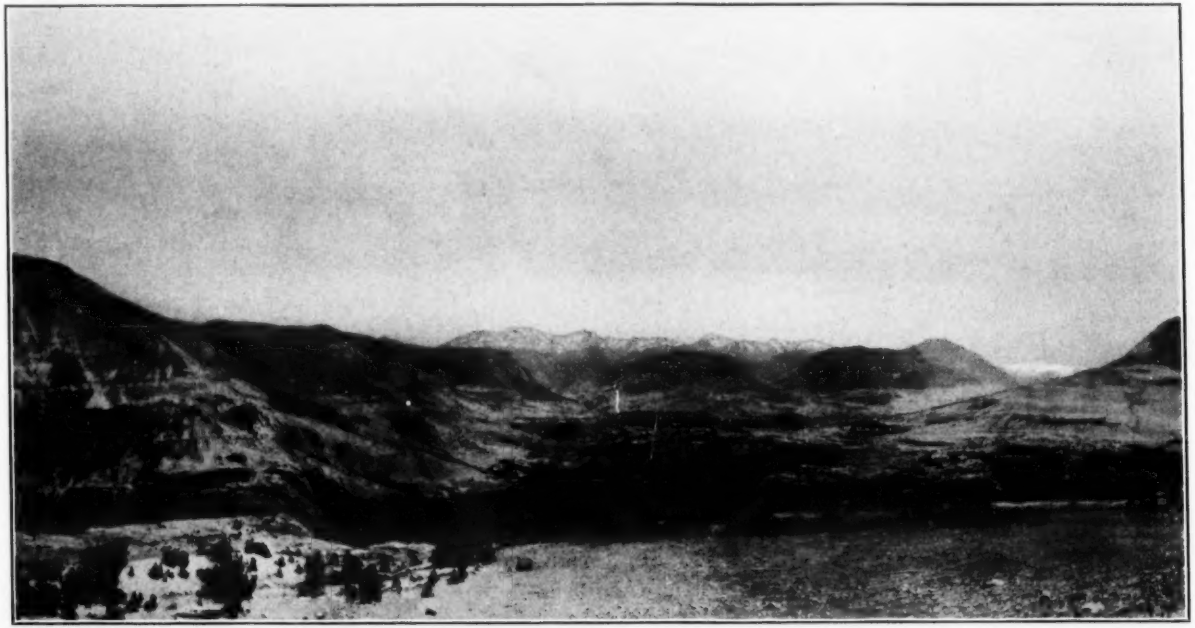
FIGURE 1.—SUN RIVER CANYON, MONTANA

View west from the plains, showing a gap in the mountain front four miles wide, above the lower wall of limestone in which is cut the portal of the canyon. The four-mile gap represents the Pliocene or early Pleistocene valley.

FIGURE 2.—VIEW NORTHEAST TO MOUTH OF THE CANYON AND OVER THE TOP OF THE LOWER WALL OF LIMESTONE FROM THE INSIDE

The bottom of the Pliocene-early Pleistocene valley was at the top of the lower wall. The narrow portal was cut through this lower wall to a depth of nearly 1,000 feet in pre-Wisconsin Pleistocene time, and the narrow inner gorge, 180 feet deep, now blocked by the United States Reclamation dam, was cut in post-Wisconsin time.

SUN RIVER CANYON



UPPER VALLEY OF CLARK FORK OF YELLOWSTONE RIVER

Showing inner box canyon (Pleistocene?) cut 1,000 to 1,300 feet in pre-Cambrian gneiss and granite below its bottom. The valley is Tertiary to early Pleistocene. This panoramic view is southwest up Sunlight Creek. Upper slopes of Paleozoic sedimentaries. Peaks of Tertiary volcanic rock of Absaroka Mountains in background.

is now cut away. In consequence of this and later uplifts, as indicated below, before the Clark Fork Glacier advanced at the Wisconsin stage the stream had cut the inner box canyon to depths of 1,000 to 1,300 feet in the pre-Cambrian gneiss and granite below the bottom of the ancient high-level valley (plate 18) and had correspondingly deepened its valley across the plains.

Early Pleistocene

Pre-Wisconsin drift of mountain glaciers and its relation to the Flaxville plain

In 1911[17] the writer described, before the Geological Society of America, the occurrence of very old glacial till capping the high benches in front of the mountains of Glacier National Park, and in 1912 Stebinger and the writer[18] presented a second paper. This glacial till, some of which is cemented by calcium carbonate to a hard tillite, caps the highest (or Number 1) Bench, which is now regarded as the physiographic correlative of the Flaxville Plain of northeastern Montana. The geographic and physiographic relations of this ancient till and of striated pebbles scattered on number 1 and number 2 benches for 20 miles out from the mountain front are such as to indicate that the first of the mountain glaciers extended out onto the Number 1 Bench, or Flaxville Plain, before it had been greatly dissected. It has been suggested that the striated pebbles on Number 2 Bench were deposited by a second and later advance of the mountain glaciers, but this has not been demonstrated. That the high-level glacial till is very old, probably as old as the Kansan or Nebraskan drift of Iowa and adjacent States, is indicated by the fact that before the mountain glaciers advanced at the Wisconsin stage the mountain gorges and their valley continuations on the adjacent plain had been deepened 1,000 feet or more largely by interglacial stream erosion, so that the relief of the mesas capped with till and gravel controlled to a considerable extent the later glacial flow.

Careful consideration of the relations of the terrace remnants along the upper Missouri and Yellowstone and their tributaries to the remnants of the high plains bordering the mountain fronts and to the ancient glacial till on the highest of these remnants in the Glacier Park region seems to warrant certain tentative conclusions, which may be summarized at this point as follows:

[17] W. C. Alden: Pre-Wisconsin glacial drift in the region of Glacier National Park, Montana. Bull. Geol. Soc. Am., vol. 23, 1912, pp. 687-708.

[18] W. C. Alden and Eugene Stebinger: Pre-Wisconsin glacial drift in the region of Glacier National Park, Montana. Bull. Geol. Soc. Am., vol. 24, 1913, pp. 529-572.

(1) The highest of the benches or terraces bordering the mountain fronts are correlatives of the Flaxville Plain of northeastern Montana.

(2) Such fossils as have been found in the Flaxville gravel indicate the development of the Flaxville Plain was not completed before Pliocene time.

(3) The presence of the Camelops tooth, which was identified by Doctor Gidley as "apparently Pleistocene," suggests that the streams may not have finished deposition of the Flaxville gravel until early Pleistocene time.

(4) The relations of the oldest drift of the mountain glaciers on the supposed remnants of the Flaxville Plain close to the mountain front lead to the inference that the Flaxville Plain had not been greatly dissected when climatic conditions became such as to bring on extensive glaciation in the mountains.

(5) This first Cordilleran glaciation was probably contemporaneous with the advance of the Keewatin ice-sheet of the Nebraskan stage and is regarded as marking the beginning of Pleistocene time.

(6) About this time the streams began cutting below the Flaxville Plain, and this, taken in connection with the initiation of Cordilleran glaciation, leads to the inference that Pleistocene time in this region was initiated by a second regional uplift. The amount and character of this uplift is discussed below (page 409).

(7) I know of no observational grounds for regarding as Pleistocene any features in this region which are older than the pre-Wisconsin glacial drift on the remnants of the Flaxville Plain in front of the mountains of Glacier National Park.

POSSIBLE PRE-WISCONSIN DRIFT OF MOUNTAIN GLACIERS

Although there are no positive evidences of early Pleistocene mountain glaciation south of Glacier Park known to the writer, there are in a few places phenomena which, though requiring further investigation, suggest the extension of the mountain ice before the high benches were greatly dissected. One of the most definite of these is near the head of Musselshell River, at the south side of Castle Mountains. Between the Chicago, Milwaukee and Saint Paul Railway, west of Lennep and Alabaugh Creek on the north, is a ridge nearly 6 miles long whose top is 200 to 400 feet above the creek. The west end of this joins the foot of the mountain near Castle, about 6,200± feet above tide. It appears to be a remnant of one of the highest benches, such as occur farther east in Musselshell Valley. The top of the ridge which was examined by the writer in 1922 and 1923 is thickly strewn with an immense number of glacial boulders.

mostly porphyry, which range in size from a foot or less to 15 feet in diameter. Weed[19] described this deposit as glacial drift. He also described a newer terminal moraine a short distance above the town of Castle, which "closes in the upper mountain valley," and states that the recent aspect of this moraine "is in marked contrast to the appearance of the adjacent boulder moraines previously noted [that is, the bouldery deposit noted above]. It fills the drainage valley and marks the front of an area in which the glacial rock-polishing and other evidences of glaciation are remarkably fresh and well preserved. Both the contrast in appearance and the relative position of this moraine, with the morainal remains found on the adjacent slopes, show that they are of very different age." After noting similar relations on Fourmile and Willow creeks east of White Sulphur Springs, he states: "These facts clearly indicate two periods of glaciation, one of which is much older than the other, the later being of much less severity."

About 12 miles up the Stillwater Canyon, in the Beartooth Mountains, northeast of Yellowstone Park, the writer found (in September, 1921) a great mass of semi-indurated glacial till banked on the side wall of the canyon 1,000 feet above the stream. As the whole range above this level was shrouded in mist, the relations of the till were not wholly determined, but the occurrence of such a mass of till so high on the side of a mountain gorge is quite unusual in the writer's experience. It may be a relic of a former high-level glaciation, before the valley was cut below the Flaxville Plain. Twenty to 25 miles east of this place and 8 miles from the mountain front (east of Roscoe) is the head of a large remnant of the Flaxville Plain, or Number 1 Bench, 5,400 feet above tide. This is capped with coarse unsorted bouldery material which resembles glacial till, though no striated stones were found in it. Many of the boulders are 3 to 6 feet in maximum diameter. This bench is 400 to 500 feet above the adjacent coulées and 200 feet higher than Number 2 Bench, which is finely preserved a few miles to the west and between here and the mountains.

For miles east of the terminal moraine near the mouth of Clark Fork Canyon, in Wyoming, the broad, flat, gravelly terrace north of the river is strewn with granite boulders 1 to 8 feet or more in diameter. But for the boulders one might take the gravelly terrace to be an outwash plain. It is, however, very unusual, so far as the writer's experience goes, to

[19] W. H. Weed: Geology of the Castle Mountain mining district, Montana. U. S. Geol. Survey Bull. 139, 1896, pp. 144-145.

See, also, W. H. Weed: Description of the Little Belt Mountains district. U. S. Geol. Survey Geol. Atlas, Little Belt Mountains folio, no. 56, 1899, pp. 3 and 7.

find any such number of large boulders in outwash outside of and so far distant from a terminal moraine. That these boulders may have been let down from a higher level by erosion is suggested by the fact that the boulders, instead of being confined to the flat, are also sprinkled over the slopes of several small hills, erosion remnants, which rise above the surrounding plain, and also by the fact that boulders up to 5 feet in length were seen on remnants of Number 2 Bench 12 miles down the valley at points about 8 miles east of the mountain front. These facts give rise to the suggestion that a pre-Wisconsin glacier may have occupied the broad upper valley of Clark Fork shown in plate 16 and may have extended out beyond the mountain front onto either Number 1 or Number 2 Bench at a time before the inner box canyon was eroded.

Evidence of pre-Wisconsin glaciation in the Big Horn Mountains, Wyoming, has been presented by Darton and Salisbury,[20] but the relations of the deposits to what are now regarded as remnants of the Flaxville Plain were not described. There is a possibility that the much-weathered bouldery deposits capping Moncrief, Bald, and North ridges at the east flank of the Big Horn Mountains may be ancient glacial deposits contemporaneous in origin with the high-level pre-Wisconsin drift in the Glacier Park region, but full consideration of the question is not undertaken in this paper. Similar to these in character and in topographic position are deeply weathered bouldery deposits capping Table Mountain near the east flank of Wind River Mountains southwest of Lander, Wyoming.

DOUBT AS TO PRESENCE OF KEEWATIN DRIFT OF EITHER NEBRASKAN OR KANSAN AGE IN MONTANA

No drift of the Keewatin glacier on the plains of Montana appears to be as old as the drift of the mountain glaciers on the high benchlands in the Glacier Park region.

The relation of the high-level mountain drift described above to the first continental, or Nebraskan, drift of Iowa and adjacent States is not definitely known. While the writer does not agree with Todd's[21] inter-

[20] N. H. Darton: Geology of the Big Horn Mountains. U. S. Geol. Survey Prof. Paper 51; U. S. Geol. Survey Geol. Atlas, Cloud Peak-Fort McKinney folio, no. 142, 1906; Idem, Bald Mountain-Dayton folio, no. 141, 1906.

The glacial phenomena described in these publications by R. D. Salisbury were studied under his direction by Eliot Blackwelder, E. S. Bastin, Frank De Wolf, W. H. Emmons, and other students.

[21] J. E. Todd: The Pleistocene history of the Missouri River. Sci., n. s., vol. 39, 1914, pp. 263-274.

See, also, Is the channel of the Missouri River through North Dakota of Tertiary origin? Bull. Geol. Soc. Am., vol. 34, 1923, pp. 469-494.

pretations in some other particulars, he may be right in drawing the west limit of the Kansan ice-sheet of Missouri River along the Couteau du Missouri in North Dakota.

The amount of erosion subsequent to the completion of the Flaxville Plain and prior to the deposition of the Keewatin drift in the trans-Missouri tracts seems entirely too great to have been accomplished in that part of Pleistocene time prior to the Kansan stage of glaciation. Though there is room for considerable difference of opinion, it seems somewhat doubtful, as indicated below, if either the first or the second, the Nebraskan or the Kansan, ice-sheet invaded Montana.

It is certain that the Missouri gorge in North Dakota and its tributaries, with the exception of the new gorge of the diverted Little Missouri River, had been eroded to their full depth prior to the extension of the Keewatin ice into and across them, but it is not known how completely the several gorges and coulées were obliterated by the mantle of drift. In at least one place northeast of Watford City, North Dakota, a thickness of 100 feet of till is present, but at most of the exposures seen by the writer in North Dakota the thickness is not over 10 or 15 feet and in many places there are only scattered drift boulders. Most of the latter can be accounted for by berg transportation on waters temporarily ponded by the ice-front in the several valleys and are not necessarily to be regarded as the residuum of the removal of a continuous sheet of till. It is not, therefore, easy to evaluate the amount of post-glacial erosion in the trans-Missouri tracts for comparison with the several pre-Wisconsin drift sheets of Iowa and adjacent States. The degree of modification of the Keewatin drift by weathering is considered below (page 413).

RENEWED UPLIFT AND DEVELOPMENT OF THE SECOND SET OF TERRACES

As stated above, a second regional uplift occurring at the close of the Tertiary caused the streams to cut into the Flaxville terraces early in Pleistocene time. The down-cutting is indicated by the vertical distance between the Flaxville Plain and the second terraces. East of the longitude of Little Rocky Mountains this is generally 500 to 600 feet. It is 300 to 400 feet around these and adjacent mountain groups and in Big Horn Basin, and 100 to 300 feet in most places near the Rocky Mountain front. Like many other geologists, I have held the opinion that the close of the Tertiary and beginning of the Pleistocene was probably marked by a notable uplift in the Cordilleran region. I am still inclined to hold that idea, and, indeed, in the preliminary abstract of this paper an uplift of the plains and mountains in this region, ranging from 500 to 1,500 feet, was postulated, and it was stated that this started the

streams to cutting below the Flaxville terrace. It must be admitted, however, that the evidence from the terraces is rather puzzling and does not clearly indicate the occurrence of such an uplift of the mountains themselves between the formation of the Flaxville and second terraces. The conditions, as shown above, were such as initiate glaciation in the mountains and cause extension of the glaciers onto the piedmont part of the Flaxville Plain. Across the plains of Montana the streams certainly cut hundreds of feet below the Flaxville Plain when developing the second set of terraces. As the Rocky Mountains are approached from the east, however, the second terraces rise to positions less far below the Flaxville Plain than might be expected if a notable uplift of the mountains actually did occur.

While there is the ever-present possibility of error in the correlation of remnants of much dissected terraces over so great an area, yet, so far as the study has been carried, the probability of such error in the case of the terraces of the second set seems not great. It is, perhaps, best at this stage of the investigation not to make too definite a postulation of the amount of uplift of the Rocky Mountains of this region which occurred at the end of the Tertiary and the opening of the Pleistocene. It is clear that there was considerable uplift after the completion of the Flaxville Plain, but it is not yet clear how much of this preceded the planation of the second terraces near the mountains. As stated above, it amounted to at least 500 or 600 feet on the plains east of the longitude of the Little Rocky Mountains. Possibly the relatively small vertical interval between the upper and second terraces near the Rocky Mountain front is due, in part at least, to the fact that many, if not all, of the mountain gorges were occupied by glaciers which extended clear out to the bordering piedmont. The presence of the ice would prevent downward stream-cutting until after the ice had melted, even if the uplift had already taken place. Other possible factors are not discussed in this paper, awaiting further study and because of a desire not to make this summary presentation too long.

The broad, smooth terraces and benchlands of this second set are evidence of a long period of planation (plate 19, figure 1). There are two levels 100 to 150 feet apart, especially on the Yellowstone and tributary valleys, which are grouped together, as they can not everywhere be distinguished. These are generally at the tops of the bluffs, 150 to 350 feet above the present valley bottoms. The lower one of these two is generally the best preserved terrace throughout the region and affords the best basis for correlation.

On the Yellowstone the second terraces are at the top of the bluffs,

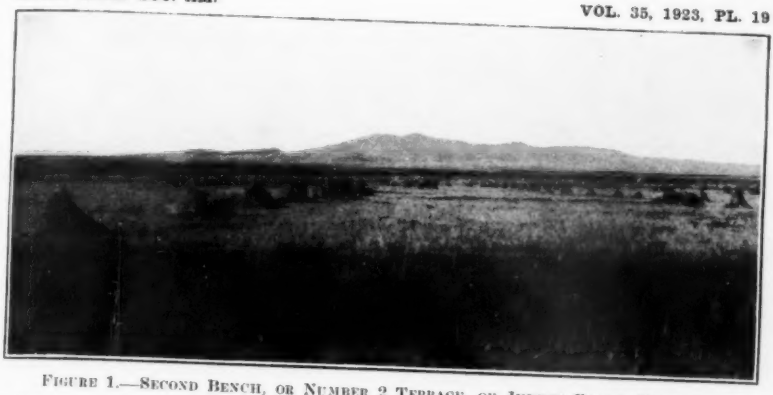


FIGURE 1.—SECOND BENCH, OR NUMBER 2 TERRACE, OF JUDITH BASIN, MONTANA
There are remnants of the Flaxville Plain high up on the left, or west flank, of South Moccasin Mountain, in the background.

FIGURE 2.—THE GREAT SECOND TERRACE AS SEEN FROM THE YELLOWSTONE TRAIL EAST OF FORSYTH, MONTANA

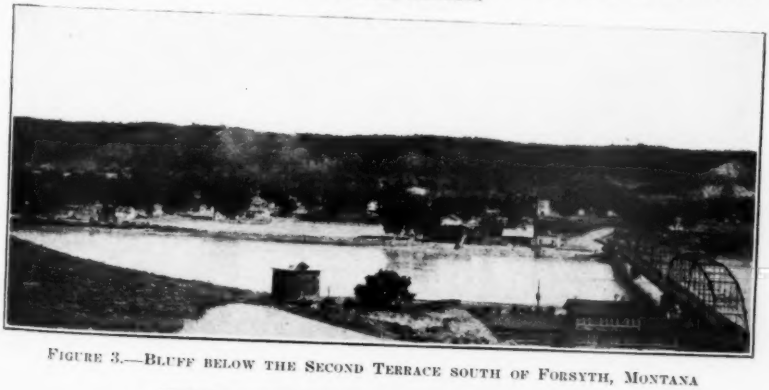


FIGURE 3.—BLUFF BELOW THE SECOND TERRACE SOUTH OF FORSYTH, MONTANA

SECOND TERRACES ON YELLOWSTONE RIVER

FIGURE 1.—NORTH FLANK OF THE LITTLE ROCKIES WEST OF HAYS POST OFFICE
Showing the great wall of upturned Paleozoic limestones.

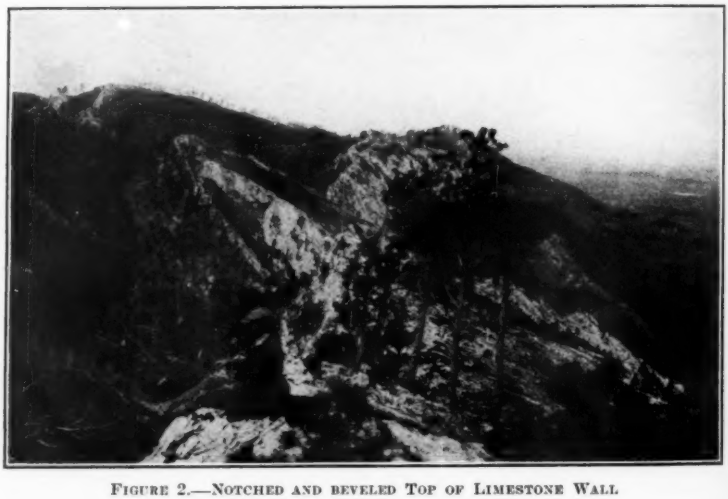


FIGURE 2.—NOTCHED AND BEVELED TOP OF LIMESTONE WALL
Here the wall rises nearly 1,000 feet above the plains.

LITTLE ROCKY MOUNTAINS, MONTANA

more than 300 feet above the river in the Glendive Quadrangle, nearly 350 feet between Terry and Fallon, about 250 feet at Miles City, and nearly 300 feet above the stream at Forsyth (plate 19, figures 1 and 2).

Judging from the remnants preserved, these early Pleistocene valley bottom lands on the Upper Missouri and on Yellowstone River were 5 to 10 miles in width—that is, fully twice as wide as at the next lower stage. Bordering the mountains, the Number 2 Terraces were like great alluvial fans between the higher gravel-capped ridges.

One thing which has tended to confusion in attempts to correlate the several terraces along the Yellowstone is that for some distance east and west of Billings the river has not cut so far below what appears to be Number 2 Terrace as it has farther to the east and to the west. After having gone back and forth along the valley in an endeavor to work out the sequence, what now seems to the writer to be Number 2 Terrace near Billings is the broad terrace about 125 feet above the river on the north side. This is probably the lower level of the Number 2 set. A reason why the river has not cut deeper below this terrace near Billings may be found in the retarding effect of the upturned Eagle, Judith River, and Lance sandstones on the eastern flank of the Pryor Mountain anticline which the river crosses.

Collier found in the drift-covered, but nonglacial, gravel on the second terrace of Milk River near Malta a tooth which Doctor Gidley referred to a horse resembling the living species. Correlatives of the lower level of number 2 terrace are Hewett's[22] "Sunshine terrace" of the Big Horn Basin and probably Blackwelder's[23] "Circle terrace" on Wind River, Wyoming. Following the shrinking of the early mountain glaciers, the streams deepened the mountain gorges and deeply trenched the piedmont part of the terraces of the second set as a result of the steepening of gradients which had already taken place.

Among the most interesting places to study the relations of the Flaxville and lower terraces are the borders of the Little Rocky Mountains, the most northeasterly of the mountain outliers. This mountain group is encircled by a great wall of upturned Paleozoic limestone several hundred to 1,000 feet in height (plate 20). Radiating from the mountains are remnants of three sets of smooth gravel-covered terraces beveled across the upturned edges of the Mesozoic strata. Of these the uppermost, which appears to represent the Flaxville Plain, is graded to the beveled top of the limestone wall (plate 21). Certainly this terrace is

[22] Op. cit.

[23] Eliot Blackwelder: Post-Cretaceous history of the mountains of central western Wyoming. Jour. Geol., vol. 23, 1915, p. 316.

the result of a very long period of erosion. The second set of terraces is also finely represented, and several hundred feet below these latter terraces the present streams issue from narrow gorges. The third set is not so well marked about the Little Rockies. There were no local glaciers in this mountain group.

PREGLACIAL COURSES OF MISSOURI AND YELLOWSTONE RIVERS AND THEIR DIVERSION

There is reason for thinking that the drainage of the plains of Montana and adjacent parts of Wyoming and North Dakota was flowing to Hudson Bay when the Flaxville Plain and correlated number 1 benches and terraces were formed, and that it continued to flow there at least until the higher level of the Number 2 set of benches and terraces was developed. Todd held that these streams flowed to Hudson Bay until diverted by the ice.[24] Bauer[25] described a broad abandoned river valley, earlier noted by Beekly, which is filled with glacial drift and which begins as a sag in the bluffs about 200 feet above Missouri River east of Poplar and extends thence northeastward to northwestern North Dakota. The exact course throughout has not yet been definitely located (see map, plate 11). Judging from the altitudes, a large river such as the Missouri was flowing northeastward in this valley when Number 2 Terrace was being formed farther west. The trend of the Yellowstone Valley below Fallon, as Bauer also pointed out, is almost directly in line with that part of the Missouri Valley between the mouth of the Yellowstone and Williston, North Dakota, and with the broad valley extending north from Williston, in which the Little Muddy now flows southward. The continuation of this valley farther north appears to be obliterated by the great deposits of morainal drift on the Missouri Couteau. It seems probable that the more rapid fall in the shorter distance to tidewater in Hudson Bay along these courses, as compared with the present route to the Gulf of Mexico, may account, in part at least, for the greater dissection of the plains of Oligocene to early Pleistocene age north of the latitude of the Black Hills and Big Horn Mountains, as compared with the plains of similar age farther south. Glacier Park is about as far from Omaha as it is from Hudson Bay.

Leonard[26] objected to the idea that the Upper Missouri and the Yellowstone River flowed to Hudson Bay in Pleistocene time, on the ground

[24] Op. cit.

[25] C. M. Bauer: A sketch of the late Tertiary history of the Upper Missouri River. Jour. Geol., vol. 23, 1915, pp. 52-58.

[26] A. G. Leonard: Pleistocene drainage changes in western North Dakota. Bull Geol. Soc. Am., vol. 27, 1916, pp. 296-299.

FIGURE 1.—UPPER TERRACE, OR FLAXVILLE PLAIN, AND SECOND, OR NUMBER 2, TERRACE, WEST OF SAINT PAULS MISSION

FIGURE 2.—FLAXVILLE PLAIN WEST OF SAINT PAULS MISSION

The plain has been graded to the beveled top of the great limestone wall, here sparsely covered with timber.

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that no deeply buried valleys leading in that direction have been definitely located. He has claimed that, inasmuch as the Missouri gorge, leading southward through North Dakota, contains pre-Wisconsin drift down to and even below the present water level, it must be preglacial in age. It is true that there is what appears to be pre-Wisconsin glacial till in and south and west of the Missouri gorge in North Dakota, so that an ice-sheet certainly crossed the gorge since it was cut. Whether or not, however, the gorge is of pre-Pleistocene age depends on the age of the pre-Wisconsin ice which crossed it. The drift has heretofore been regarded as of Kansan age.[27] I have examined many exposures of Kansan and pre-Kansan drift in Iowa and Nebraska and I have seen numerous exposures of the drift in and south and west of the Missouri gorge in North Dakota and Montana. I have nowhere seen evidence of so great modification of this latter drift by weathering as is generally plainly evident on Kansan or Nebraskan drifts farther south. Whether this difference is wholly due to difference in age, or whether it is largely due to climatic differences, I am unable to state; but, by reason of this difference and for other reasons, it seems to me quite possible, if not probable, that the Keewatin ice did not cross the present gorge of the Missouri in either Montana or North Dakota until the Iowan stage of glaciation. I am, therefore, as stated below, tentatively regarding this trans-Missouri drift in these latter States as younger than Kansan and possibly of Iowan or late middle Pleistocene age. Upper Missouri River was probably turned southward through the Dakotas in early Pleistocene time by the advance of either the Nebraskan or Kansan ice. With it was diverted the Lower Yellowstone. These streams were not then flow-

[27] A. G. Leonard: The pre-Wisconsin drift of North Dakota. Jour. Geol., vol. 24, 1916, pp. 521-532.

In a letter to the present writer dated January 25, 1923, Doctor Leonard writes as follows:

"Regarding the age of the pre-Wisconsin drift, I have of late years been inclined to regard it as probably older than the Iowan on account of the great erosion it has undergone west of the Missouri River. This older drift in that region is generally represented by gravel and boulders which I have regarded as residual, and only in relatively few places have I found any boulder clay. Such great erosion I have thought indicated a drift at least as old as the Kansan. I realize that this old drift does not resemble in color that of southern Iowa, but I believe the difference in climate may account for this.

"It is partly because I believe the older drift to be Kansan that I have regarded the Missouri Valley in North Dakota as preglacial. I do not think the river would have had time to erode such a valley after being diverted by the first ice invasion before the Kansan drift was deposited in the valley. If the pre-Wisconsin drift is of Iowan age, there would probably have been time for the Missouri to erode its valley between the time of the first ice invasion and the deposition of the Iowan drift. I do not, however, believe that there is any evidence that the Missouri ever flowed east or northeast from the bend at the mouth of Snake Creek. If it once flowed into Hudson Bay, I should favor the view that it was by way of the old valley near Poplar."

ing at lower levels than at present, but at levels 200 feet or more higher on the valley bottoms now represented by the second terraces.

Later Pleistocene

THIRD SET OF TERRACES

Following the completion of the second set of terraces and the diversion of Missouri and Yellowstone rivers by the Keewatin ice-sheet in North Dakota, there appears to have been a third general and somewhat notable uplift of both mountains and plains, succeeded by a period of valley broadening. This caused the streams to cut down 500 feet or more in and near the mountains and 300 to 150 feet farther out, and then to develop a third set of terraces between the lines of bluffs. Where preserved, these terraces are generally 50 to 100 feet above the present streams, but in many places the streams have cut 100 to 300 feet below them. They appear to be older than any of the Keewatin drift on the Montana plains and are clearly older than the well marked moraines of the mountain glaciers of the Wisconsin stage of the Glacier Park region. In places farther south the relation is obscured by erosion or by the deposition of outwash gravels bordering the moraines.

With the gravel on the Number 3 Terraces perhaps may be correlated the so-called "Saskatchewan gravel" described by Dawson and McConnell,[28] and later, in 1912, by Stebinger and Alden.[29] This underlies the glacial drift in places on the streams in southern Alberta. There is similar buried gravel on Missouri River in the region of Fort Benton, and on Milk River near and east of Havre. On Missouri River, below the mouth of Milk River, there is also some nonglacial river gravel covered with glacial till, as also near Malta and at Wolf Point, and there are considerable remnants of a terrace about 100 feet or so above the river in eastern Montana and North Dakota (as at Nesson). The third terrace is also well marked on the Yellowstone near and below Terry, where it is traversed in places by the main roads, railways, and irrigation canals. There are some other remnants farther upstream and on the tributaries; also on the Upper Musselshell, in Judith Basin, on Sun River, and in Blackfeet Indian Reservation east of Glacier Park.

In the latter place the relations show clearly that number 3 terrace was developed and in its turn dissected prior to the extension of the mountain glaciers at the Wisconsin stage of glaciation. West of Cutbank

[28] G. M. Dawson and R. G. McConnell: Glacial deposits of southwestern Alberta in the vicinity of the Rocky Mountains. Bull. Geol. Soc. Am., vol. 7, 1895, pp. 31-66.

[29] W. C. Alden and Eugene Stebinger: Pre-Wisconsin glacial drift in the region of Glacier National Park, Montana. Bull. Geol. Soc. Am., vol. 24, 1913, pp. 558-572.

the flat, gravel-covered bench known as Carlow Flat is traversed by the Great Northern Railway. Here it spreads out broadly to an extent of more than 50 square miles and slopes away from the terminal moraine of the great Two Medicine Glacier like an outwash plain. A few miles south of the railway, however, the bench is cut through by Flat Coulée, an abandoned stream valley now traversed by the irrigation canal. This coulée is about 200 feet deep and nearly 2 miles wide. Stebinger traced the clearly marked terminal moraine off the bench, down one side, across the broad bottom of the coulée and up the opposite slope, showing that the gravel plain was there and dissected some time before the moraine was formed. This Number 3 Bench, or Terrace, is 500 to 600 feet lower than the Number 2, set closer to the mountains. Probable correlatives of the third terraces are Hewett's[30] "Greybull terrace," in Big Horn Basin, and Blackwelder's[31] "Lenore terrace," on Wind River, Wyoming.

IOWAN (?) STAGE OF GLACIATION AND STREAM DIVERSION

As indicated above, what may have been the first invasion of Montana by the Keewatin ice-sheet occurred after Missouri River had eroded its gorge through the Dakotas and after the development of the third set of terraces. This ice invasion diverted the Missouri in Montana from what is now, in part, the Milk River Valley on the north side of the Bearpaw and Little Rocky Mountains to the present course on the south side of these mountains. This may have occurred as late as the Iowan stage of glaciation. If this is correct, it will necessitate some change in the glacial map of Montana and North Dakota where the outer drift has been considered Kansan. There were probably glaciers in the mountains at the same time, but no clear evidence of this has been found.

Evidently there was renewed regional uplift and downward cutting by the streams after Number 3 Bench was formed. Terraces of the Number 3 set are found in the Missouri gorge in North Dakota, and, as stated above, there is glacial till there down to and below the water level and also in the valleys and on the uplands for 30 to 40 miles or more to the south and west. The glacier diverted the lower course of Little Missouri River to the eastward in North Dakota, and since that time the stream has cut a gorge 400 to 500 feet deep in the Fort Union shales and sandstones. In Yellowstone Valley the ice extended up to Intake, about 15 miles below Glendive, but could not override most of the high remnants of the Flaxville Plain on the west; so that the glacial margin recurved northward 25 or 30 miles and then extended westward. There is glacial

[30] Op. cit.
[31] Op. cit.

till in eastern Montana for 10 or 15 miles south of Missouri River and scattered boulders are found beyond that. The actual limit of the ice-advance has not been definitely mapped through most of the extent between Yellowstone River and Little Rocky Mountains. Here the Missouri was temporarily diverted by the ice, so that the water found an outlet eastward to a lake in Yellowstone Valley through the pass now traversed by the Richey Branch of the Great Northern Railway, and escaped thence eastward to the Little Missouri. It is not known just how far up Musselshell Valley the ice extended, but there are granite boulders 5 or 6 miles south and west of Mosby and there is a boulder-strewn belt 15 to 20 miles wide south of the Little Rockies on the south side of the Missouri, as mapped by Calhoun and later by Reeves. The erratics in this belt may all have been dropped from ice floating on a temporary glacial lake, as no till has been found. The lower and earlier course of Musselshell River (now followed by Beaver Creek) was partially filled with drift and was transected and cut off by the new gorge of Missouri River when the marginal waters subsided. The ice-margin probably encircled the combined Little Rockies and Bearpaw Mountains on the east, north, and west, as at the later or Wisconsin stage.

West of the Bearpaws an ice lobe more than 100 miles wide crowded Missouri River southward onto the high plain north of Highwood Mountains, as shown by Weed and Calhoun, and held it there while it eroded a valley 200 to 300 feet deep, now known as the Shonkin Sag (plate 22, figure 1), and traversed by the Great Falls Branch of the Chicago, Milwaukee and Saint Paul Railway. When the ice-front receded, this valley was abandoned and the Missouri finally located in its present course, south of the Bearpaws and Little Rockies. Shonkin Sag was the outlet of a large temporary lake occupying Missouri and tributary valleys in front of the ice-margin. Scattered Laurentian crystalline boulders in these valleys were dropped from ice floating on this body of water, to which Calhoun[32] applied the name Great Falls Lake.

There is little evidence in hand concerning the Peorian stage of deglaciation in this region. There was some weathering and erosion of the drift, but no notable deposition of loess as farther south.

EARLY WISCONSIN STAGE OF GLACIATION

Following the Peorian stage of deglaciation the Keewatin ice-sheet readvanced into Montana at the early Wisconsin stage of glaciation, but it probably did not quite reach Missouri River. There is no clear evidence in hand that uplift in this region either immediately preceded or

[32] Op. cit., pp. 40-44.

FIGURE 1.—SHONKIN SAG

A glacial diversion channel of Upper Missouri River near the north flank of Highwood Mountains, Montana.

FIGURE 2.—MISSOURI RIVER GORGE BELOW GREAT FALLS, MONTANA

The inner gorge at this point just below Big Falls is about 180 feet deep below an upper drift-covered slope. This gorge has been cut since the diversion of the river by the pre-Wisconsin ice-sheet.

attended this glacial advance. About the north flanks of the Little Rockies and the Bearpaw Mountains the limit of the Keewatin ice at this stage is fairly well marked.

The approximate location of the ice-limit east of the Little Rockies, as shown on the map (plate 11), is based on several factors. There is no doubt that there is drift of Wisconsin age in northwestern North Dakota and in a few of the most northeasterly townships in Montana. Further, there can be little or no doubt that Wisconsin drift covers the great area indicated on the map west of the longitude of Malta. Repeated criss-crossing of the area between Malta and the North Dakota line failed to reveal any definite terminal moraine connecting what has been known as the Altamont moraine in northwestern North Dakota with the limit of the Wisconsin drift at and west of the Little Rocky Mountains. The occurrence of morainal deposits outside of what appears to be the main front of the Altamont moraine near and east of Ray, North Dakota, taken in connection with conditions to the west, suggests that an early Wisconsin drift emerges here from beneath the Altamont moraine. The margin of an ice-sheet extending southward to these emerging morainal deposits would probably be characterized by a considerable reentrant where it lay across the high upland remnants of the Flaxville Plain, in Roosevelt, Daniels, and Valley counties, in northeastern Montana. The altitude near Opheim reaches about 3,350 feet above tide (barometric), and that of the Wood Mountain upland to the north, in southern Saskatchewan, rises perhaps 100 feet higher; so that it must have formed a considerable obstacle to the margin of an advancing ice-sheet.

West of this high country and north of the Larb Hills, Frenchman Creek, and other streams of northern Valley and Phillips counties, together with the preglacial Missouri River, eroding the area of the Bowdoin dome, had long previously developed a broad basin with uneven dissected surface, ranging from several hundred to a thousand feet lower in altitude than the upland to the east. In this basin the early Wisconsin ice-sheet would probably have extended much farther southward. The presence of what appears to be Wisconsin drift about the north margin of the Little Rockies is presumptive evidence that the glacier did so extend. There should be further and more detailed study of the phenomena along the line shown on the map as the "approximate margin" of the early Wisconsin drift. There are now known to be discontinuous morainal deposits in places along this line, and their presence is one reason for locating the boundary as shown. The present mapping of this and numerous other physiographic features of this region is subject to revision.

North of the Little Rocky Mountains the ice overtopped some outlying buttes 850 to 1,000 feet high, and it pushed southward on the upper bench near Lodgepole to a position which is now 3,500 feet above tide.

At this early Wisconsin stage there was a great lobe of ice more than 100 miles wide west of the Bearpaw Mountains. The top of Square Butte east of Big Sandy, within a few miles of the glacial limit, is sprinkled with Laurentian crystalline boulders, and clearly marked glacial striæ were seen on ledges 1,000 feet above the adjacent plain. At only one place (south of Conrad) did this glacial lobe override the eroded end of one of the high remnants of the Flaxville Plain, but north of Marias River it overtopped the 600-foot escarpment of Eagle sandstone and crowded west a few miles onto the upland. The marginal moraine of this lobe is in part very finely developed and in part poorly marked. At one point on this upland north of Cutbank the terminal moraine attains its highest elevation in the United States—that is, 4,460 feet above sealevel. Curving sharply about this high point, the drift margin descends 500 feet to Milk River in ten miles and extends in a sinuous line to and across Saint Mary, Belly, and Waterton rivers, and thence northward near the front of the Canadian Rockies. The ice entirely surrounded the Sweetgrass Hills 35 to 55 miles to the east, but did not overtop them. Calhoun[33] found that the three buttes, whose crests are 6,000 to 6,800 feet above tide, must have stood as nunataks, the highest of them rising 2,000 feet above the surrounding ice. Whether or not the plateau tops of the Cypress Hills were entirely overriden by the ice is not known. On the top of the western segment, which stands about 4,800 feet above tide or higher at the western end, the writer did not observe any glacial drift. This plateau is about 2,000 feet higher than Milk River at the International Boundary.

There were temporary glacial lakes formed in several of the valleys, due to ponding of the water by the ice-front, and in these basins are scattered Laurentian crystalline boulders dropped from floating ice at either this or the earlier stage of glaciation or both. During the recession of the ice-front several well marked moraines were formed. Two of these are north of Milk River, in Blaine and Phillips counties.

Calhoun[34] has discussed the relations of the deposits of the Keewatin ice-sheet to those of the several mountain glaciers which protruded onto the piedmont from the canyons of Sun River and streams farther north. More detailed mapping of these has since been done, mostly by Stebinger and partly by the present writer. The writer has also examined the

[33] Op. cit., p. 56.
[34] Op. cit.

terminal moraines of most of the eastern Rocky Mountain glaciers farther south, within the region under discussion (see map, plate 11), excepting most of those on the Big Horn Mountains.[35] The phenomena of the mountain glaciers can not be described within the limits of the present paper. One of them, the Two Medicine Glacier, spread over 800 square miles of the plains of Blackfeet Indian Reservation. It is probable that the outer moraines were formed at the early Wisconsin stage of glaciation. In many cases there are, one to several miles within the outermost moraines, second sets of well marked moraines which may perhaps represent the extent of the glaciers at the time of the later Wisconsin advance.

Reference is made above to the very large amount of erosion which was accomplished after the completion of the Flaxville Plain and the first glaciation of its piedmont margin. The relations of the later glacial deposits show that the canyon deepening was almost wholly accomplished prior to the Wisconsin stage of glaciation. Many of the mountain gorges were deepened 1,000 feet or more. The relief developed was so great that in very few places did the piedmont glaciers overtop the remnants of the Flaxville Plain. The erosion out on the plains was somewhat less deep, but areally very extensive, as shown by the map (plate 11).

Although a belt 30 to 50 miles wide adjoining the International Boundary has been crisscrossed on a dozen different routes in southern Saskatchewan, the writer has failed to find that the great moraine known as the Altamont moraine reenters Montana after extending from the northeastern townships of the State into Saskatchewan. It has therefore been concluded that the Keewatin ice-sheet encroached on Montana but a few miles at the later Wisconsin stage. Its deployment here and in North Dakota appears to have been in large measure controlled and limited by the height of the Couteau du Missouri above the lower plain

[35] For description see:

W. H. Weed: The glaciation of the Yellowstone Valley north of the Park. U. S. Geol. Survey Bull. 104, 1893.

W. H. Weed and L. H. Pirsson: Geology of the Castle Mountain mining district, Montana. U. S. Geol. Survey Bull. 139, 1896.

N. H. Darton: Geology of the Big Horn Mountains, Wyoming. U. S. Geol. Survey Prof. Paper 51, 1906, chapter on glaciation by R. D. Salisbury and assistants.

G. R. Mansfield: Glaciation in the Crazy Mountains of Montana. Bull. Geol. Soc. Am., vol. 19, 1907, pp. 558-567.

C. L. Dake: Glacial features on the south side of Beartooth Plateau, Wyoming. Jour. Geol., vol. 27, 1919, pp. 128-131.

Arthur Bevans: Summary of the geology of the Beartooth Mountains, Montana. Jour. Geol., vol. 31, 1923, pp. 456-457.

See, also, the following folios of the U. S. Geol. Survey Geol. Atlas: Little Belt Mountains, no. 56; Livingston, no. 1; Absaroka, no. 52; Bald Mountain-Dayton, no. 141; Cloud Peak-Fort McKinney, no. 142.

to the east, although that escarpment was clearly overtopped and overridden 10 to 20 miles or more. In the northwestern counties of North Dakota the height of the couteau is 300 to 400 feet.

LATE PLEISTOCENE OR RECENT UPLIFT?

The question has arisen as to whether there is any evidence of uplift having occurred in this region in connection with or since the Wisconsin stage of glaciation. There is no very definite evidence bearing on this now in hand. Almost everywhere the streams appear to be actively cutting downward. The depths of post-Wisconsin erosion range from 50 feet or less to 100 feet or more on the plains, and some of the mountain canyons, as on Sun River, have narrow, tortuous gorges cut to depths of 100 to 200 feet in their bottoms. Milk River is wandering about and tying itself in bowknots on a valley fill because it can not cut down faster than does the Missouri, to which it is tributary. The latter stream cut across cols west of the mouth of Milk River following its relocation after the pre-Wisconsin (Iowan?) stage of glaciation and has cut a great trench in shale and sandstone 100 to 500 feet in depth, but it is not evident how much of this has been cut in post-Wisconsin time. Below the city of Great Falls it plunges over a series of cascades and rapids, descending 612 feet in 12 miles of its new course (plate 22, figure 2). Above the city it is meandering on a valley fill. It is not certain just how much of this depth of erosion has occurred since the early Wisconsin glaciation, inasmuch as that ice-sheet is not known to have crossed or diverted the river. Taken altogether, the streams certainly have not yet had time to reach the limit of downcutting and do any considerable amount of lateral planation since the last regional uplift.

There are certain facts that are not clearly evaluated, but which suggest that a differential regional uplift with easterly or northeasterly tilt has occurred since the early Wisconsin ice invasion, if not since later Wisconsin glaciation. It is noted that there is a gradual westerly increase in the present altitudes of points west of Minnesota which were just high enough to stop the advance of the Wisconsin ice-front. These facts may be cited for consideration as to what they are worth. It is quite possible that there are in some places, if not in all, modifying factors that should be taken into consideration for their true interpretation.

(1) It is noted that the altitude at the head of the Couteau des Prairies, the great wedge which separated the Des Moines lobe from the Dakota lobe of the Keewatin ice, is about 2,000 to 2,100 feet above tide in northeastern South Dakota.

(2) A few miles north of the line between North and South Dakota, on the west side of the Dakota lobe, the ice-front reached elevations which are now 2,100 to 2,200 feet above tide, and then stopped on top of the Couteau du Missouri, forming a reentrant, south of which, on the lower ground, it advanced 60 miles farther west.

(3) Near Stanley, where the margin of the early Wisconsin drift swings west, on top of the couteau, in northwestern North Dakota, the elevation is about 2,260 feet above tide. Higher points on the couteau reached by the later Wisconsin ice stand 2,300 to 2,400 feet above tide or more, but the ice did not extend much beyond them.

(4) On the Flaxville Plain near Opheim, in northeastern Montana, where there was probably the head of a great reentrant in the early Wisconsin ice-margin, barometric readings indicate an altitude of 3,200 to 3,300 feet above tide.

(5) At the north side of Little Rocky Mountains the limit of the early Wisconsin drift on high remnants of the Flaxville Plain near Lodgepole is 3,500 feet above tide.

(6) Northeast of Chouteau the west limit of the advance is about 3,800 feet above tide.

(7) North of Cutbank the points which caused reentrants 8 or 10 miles deep in the ice-margin now stand 4,200 to 4,400 feet above tide.

Were these several altitudes west of Minnesota the elevations of the shoreline of a great lake or sea, they would certainly be regarded as indicating subsequent tilting of the land. Although such an explanation is not so strictly applicable in the case of the edge of an ice-sheet, the present westerly increase in these altitudes is worthy of consideration, as suggesting, if not proving, that such tilting, with uplift of the mountain belts, has occurred since early Wisconsin time. Any inferences regarding regional tilting which may be drawn from the above data must also be checked with the results of studies by Upham, Tyrrell, Dowling, McInness, and Johnston of the southward tilting of beaches of Lake Agassiz during and since the retreat of the fronts of the ice-sheets of the Wisconsin stage.

Postglacial marine deposits are reported as found up to elevations 500 to 600 feet above tide in the valleys draining to the south and west shores of Hudson Bay. In this connection it may be noted that any southerly tilt or reduction of seaward slope of the land between Hudson Bay and southeastern South Dakota, which occurred subsequent to the southward diversion of Missouri River through the Dakotas, especially if it occurred about the same time as uplift of the plains and mountains of Montana and Wyoming, would tend to accelerate cutting along the Missouri and

the Yellowstone and all of their tributaries. Uplift in the Hudson Bay region must, however, have tended to retard erosion on Red, Nelson, and Saskatchewan rivers. Whether or not there is evidence of any such retardation on these streams is not discussed in this paper.

Summary

The correlations and conclusions presented in this paper may be regarded as tentative, but the writer feels fairly well satisfied that most of them will be found not to be greatly in error.

1. As indicated by the coarse Oligocene river gravel and fossiliferous sands on Cypress Hills and by other similar deposits tentatively correlated therewith, the Rocky Mountains of Montana and Wyoming and the Northern Great Plains were, by Oligocene time, sufficiently high to afford strong stream gradients for hundreds of miles to the east and northeast.

2. There are throughout the region remnants of a succession of well marked gravel-covered alluvial terraces and benchlands which may be grouped into three sets successively lower in altitude and younger in age than the Cypress Plain.

3. These were originally miles in width, smooth and flat, and they bevel the upturned edges of limestones, shales, and sandstones ranging in age from Mississippian to Eocene, showing that they are the product of stream erosion and deposition during successive long periods of still-stand or freedom from uplift or deformation.

4. They are separated by vertical intervals ranging from 100 to 600 or 800 feet, so distributed in general as to indicate that the periods of planation alternated with periods of regional differential uplift which rejuvenated all the streams and caused them to cut to successively lower levels.

5. The first set below the Cypress Plain, which is correlated with and includes the Flaxville Plain of Collier and Thom, was probably completed in Pliocene time.

6. Onto the piedmont part of the Flaxville Plain the first known Rocky Mountain glaciers of this region extended before the plain was greatly dissected. The initiation of this glaciation and the uplift which probably attended it mark the beginning of Pleistocene time.

7. It is not certain that the Keewatin ice-sheet crossed the Couteau du Missouri and invaded Montana as early as the Kansan stage of glaciation.

8. The Upper Missouri and Yellowstone rivers probably originally flowed to Hudson Bay and continued to flow there until the formation

of the second, or number 2, set of terraces. Then their combined waters were finally diverted southward through the Dakotas by either the Nebraskan or the Kansan advance of the Keewatin ice-sheet.

9. Following the erosion of the Missouri gorge in North Dakota, the Keewatin ice-sheet advanced to and across this gorge and in Montana it diverted Missouri River from the north side to the south side of Bearpaw and Little Rocky Mountains. It extended nearly to the site of Great Falls and diverted Missouri River in that vicinity.

10. This incursion of the Keewatin Glacier may perhaps have been as late as the Iowan stage of glaciation, judging from the very large amount of erosion which occurred previously during Pleistocene time and judging from the relatively small amount of erosion and modification of the pre-Wisconsin Keewatin drift since its deposition.

11. At the early Wisconsin stage of glaciation the Keewatin ice-sheet covered most of the area north of the present channel of Missouri River and extended southwestward nearly to Great Falls, Montana. It reached some points which are now 3,500 to 4,450 feet above tide.

12. At the later Wisconsin advance the Keewatin Glacier extended but 10 to 40 miles into the northeastern townships of Montana.

13. Topographic relations show that following the time of deposition of the high-level pre-Wisconsin drift of the Rocky Mountain glaciers on the piedmont portion of the Flaxville Plain in early Pleistocene time, and before these glaciers readvanced at the early Wisconsin stage, canyon-cutting to depths of 1,000 feet or more occurred and valleys were eroded across the plains to depths ranging from 1,000 feet near the mountains to 500 feet or more in eastern Montana.

14. Certain phenomena suggest that the regional uplifts continued through Pleistocene into Recent time.

15. The depths of Recent stream erosion range from 50 to 200 feet, and in general the streams appear to be actively cutting downward now.

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TERTIARY HISTORY OF THE NORTH ATLANTIC OCEAN[1]

BY WENDELL P. WOODRING

(*Read before the Society December 29, 1923*)

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INTRODUCTION

The Miocene deposits of the West Indies and Central America are famous for molluscan faunas having the richness and brilliancy characteristic of tropical faunas. Probably more than 2,000 species of mollusks have already been collected from these deposits, but not more than half of them have been described. The middle Miocene (Helvetian) beds usually carry larger faunas than other Miocene deposits. Middle Miocene faunas of 400 to 600 species have been discovered in the Dominican Republic, Jamaica, Costa Rica, and Panama.

SIMILARITY OF WEST INDIAN AND MEDITERRANEAN MIOCENE MOLLUSKS

Most of the tropical Miocene faunas from the West Indies and Central America are different from the subtropical and temperate faunas of the same age along the Gulf and Atlantic coasts of the United States. The lower Miocene (Burdigalian) faunas of the West Indies resemble the subtropical fauna of the Chipola marl (Burdigalian) of Florida; but the West Indian middle Miocene (Helvetian) faunas are more similar to younger or older subtropical faunas from the Gulf and Atlantic States than to the temperate middle Miocene faunas of the Atlantic States.

[1] Published by permission of the Director, U. S. Geological Survey, and of the Carnegie Institution of Washington.
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They more closely resemble the subtropical faunas of the Chipola marl, the Duplin marl (Pontian) of North Carolina, and the Caloosahatchee marl (Pliocene) of Florida than the temperate faunas of the Oak Grove sand (Burdigalian), the Shoal River marl (Helvetian), and the Choctawhatchee marl (Tortonian), all of Florida. The fauna of the Caloosahatchee marl is more tropical than any other Miocene or Pliocene fauna from eastern United States, and, though of Pliocene age, is more similar in general features to the West Indian middle Miocene faunas than any other fauna from eastern United States. This relation is an illustration of the principle that tropical and subtropical faunas of different ages are more similar than tropical and temperate faunas of the same age.

The similarity of the West Indian Miocene mollusks to those of the same age in the Mediterranean region was observed as early as the middle of the nineteenth century, when the West Indian fossils were first studied. As these early writers—Moore, Sowerby, and Guppy—were Europeans, it was, perhaps, natural for them to see European resemblances in the West Indian fossils. They compared them with the Miocene fossils from the Aquitaine basin of France and the Piedmont basin of Italy. According to recent work, the West Indian and Mediterranean Miocene mollusks are more similar than had formerly been supposed. The similarity to the Miocene mollusks of the Piedmont basin of Italy is particularly striking.

The similarity of the Miocene mollusks from the West Indian and Mediterranean regions, based on quantative graphic representations of the composition of the faunas, is discussed in the same detail elsewhere.[2] This similarity reached its culmination during Helvetian time, when the Miocene transgression of the sea was at its maximum in both regions. The Mediterranean faunas have a temperate element unknown in the West Indian faunas, giving them a subtropical aspect. The most striking feature of the Mediterranean faunas is their large percentage of exotic genera. Many of these exotic genera are now living in the West Indian region and are common West Indian Miocene fossils. Others, which also occur in the Miocene deposits of the West Indies, are living in West Indian and west African waters. Some genera that now are confined to the Pacific or Indian ocean and some extinct genera occur in the Miocene deposits of both regions.

Most of the exotic West Indian Miocene genera are now living in the Pacific or Indian ocean. A few exotic genera in the West Indian Mio-

[2] W. P. Woodring: West Indian, Central American, and European Miocene and Pliocene mollusks. Bull. Geol. Soc. America (awaiting publication).

cene faunas, which are common Mediterranean Miocene fossils, are living in European or west African waters, but not in the West Indies.

Although the Miocene faunas of the two regions are remarkably similar in some features, the West Indian faunas are clearly West Indian and the Mediterranean faunas have an unmistakable European aspect. Some genera that are very common in either region have never been found fossil or living in the other region.

Interpretation of the Similarity

It seems unreasonable to believe that so many indistinguishable genera, representing many families, in the two regions are the result of a similar unfolding of genetically unrelated stocks. Therefore it is assumed that these genera are genetically identical and that their occurrence in both regions is the result of migration. The known distribution and history of many of these mollusks show that they could not have migrated around the northern border of the present Atlantic basin during Miocene time. Miocene deposits on both sides of the Atlantic north of the Mediterranean and West Indian regions—in Belgium, north Germany, and the middle Atlantic States of the United States—have been as fully exploited as those farther south. They have temperate faunas, and many of the tropical and subtropical genera in the Miocene faunas of the Mediterranean region and the West Indies have never been discovered in them. The difference between tropical or subtropical and temperate faunas during Miocene time was almost as striking as it now is.

Many genera of animals and plants have a similar anomalous former or present distribution. It usually is the result of a former more cosmopolitan distribution when climatic geographic provinces were not so marked. Such a history explains the presence of some genera—such as *Spondylus, Lyria, Harpa, Xancus, Vasum, Melongena, Sconsia,* and *Strombus*—in the tropical and subtropical Miocene faunas of the West Indian and Mediterranean regions and their absence in the temperate Miocene faunas farther north. They are tropical genera isolated after a more extensive distribution around the borders of the north Atlantic during Eocene and Oligocene time.

Many genera in the Miocene deposits of the West Indian and Mediterranean regions have never been found in deposits older than Miocene on both sides of the Atlantic, although some occur in beds older than Miocene on one side, probably indicating their place of origin. Therefore their anomalous Miocene distribution is not the result of a former more extensive distribution followed by isolation. The following is a list of

these tropical and subtropical genera occurring in the Miocene deposits of the West Indies and Mediterranean region, but not in the temperate Miocene faunas on both sides of the north Atlantic and not in pre-Miocene deposits on both sides. The earliest known appearance on both sides of the Atlantic is given for each genus. Some of these genera occur in the subtropical Miocene deposits of Florida, but their presence there has no bearing on the transatlantic migration. Others, as explained in the footnotes to the list, occur in temperate Miocene faunas on one side of the Atlantic. Unpublished information is explained by remarks in the footnotes.

Genus.	Earliest appearance.	
	America.	Europe.
Leda (Jupiteria)	Miocene [a]	Oligocene [b]
Tindaria	Miocene [c]	Miocene
Malletia	Miocene [d]	Miocene
Barbatia (Obliquarca)	Miocene [e]	Eocene
Noetia	Miocene [f]	Miocene [g]
Deuteromya (= Dimya)	Miocene	Eocene
Julia	Miocene	Miocene
Carditopis [h]	Miocene	Miocene
Codakia (Codakia)	Miocene	Eocene
Myrtæa (Myrteopsis)	Miocene [i]	Miocene
Miltha (Megaxinus) [j]	Miocene	Miocene

[a] Represented by several new species in the Bowden formation of Jamaica.

[b] Represented by *Leda corbuloides* von Koenen and *L. nana* von Koenen in the north German lower Oligocene and by the type and other species in the Miocene and Pliocene of the Piedmont basin.

[c] Represented by a new species in the Bowden formation of Jamaica.

[d] Represented by an undescribed species in the Gurabo formation of the Dominican Republic.

[e] Represented by several new species in the Bowden formation of Jamaica.

[f] Also occurs in temperate Miocene faunas of middle Atlantic States.

[g] Represented by "*Anadara*" *okeni* (Mayer) in the Aquitanian and Burdigalian of Aquitaine and the Helvetian of Touraine.

[h] Not a strictly tropical genus. Cossmann has suggested that *Triodonta clara* von Koenen and *T. deleta* von Koenen, from the north German lower Oligocene, are species of *Carditopsis*.

[i] Represented by a species in the Bowden formation of Jamaica.

[j] *Pseudomiltha*, in part, of Americans; also occurs in temperate Miocene faunas of middle Atlantic States.

Genus.	Earliest appearance.	
	America.	Europe.
Phacoides (Linga) [k]	Eocene	Miocene
Phacoides (Pleurolucina)	Miocene	Miocene [l]
Tivela	Miocene	Miocene
Chione (Timoclea)	Miocene [m]	Miocene
Donax (Paradonax)	Miocene [n]	Miocene
Jouannetia	Miocene [o]	Eocene
Terebra (Terebra)	Miocene	Miocene [p]
Terebra (Fusoterebra)	Miocene	Miocene
Halia	Miocene	Miocene
Cancellaria (Bivetia)	Miocene	Miocene [q]
Cancellaria (Aphera)	Miocene	Miocene
Euthria	Miocene [r]	Oligocene
Strombina	Miocene	Eocene
Metulella	Miocene	Miocene [s]
Lampusia	Miocene	Miocene

[k] *Phacoides* (*Here*), in part, of Americans; also occurs in warm temperate Duplin (Pontian) marl of North Carolina.

[l] Represented by "*Here*" *miobarbieri* Sacco in the Helvetian of the Piedmont basin.

[m] Also occurs in warm temperate Duplin (Pontian) marl of North Carolina.

[n] Represented by a new species in the Bowden formation of Jamaica.

[o] Represented by a species in the Bowden formation of Jamaica.

[p] Some of the Piedmont basin species described as *Subula* probably represent *Terebra* (*Terebra*).

[q] Also occurs in the north German Miocene.

[r] Represented by an undescribed species in lower Miocene deposits near Santa Rosa, Isthmus of Tehuantepec, Mexico.

[s] Represented by "*Thiarinella*" *compta* (Bronn) in the Helvetian, Tortonian, and Plaisancian of the Piedmont basin.

Genus.	Earliest appearance.	
	America.	Europe.
Distorsio	Eocene	Miocene
Bursa	Miocene	Miocene
Malea	Eocene	Miocene
Pustularia	Miocene	Eocene
Cheilea	Miocene	Oligocene

This list could be expanded by including some genera whose known geologic history apparently is incomplete. The small genus *Limea* is represented in Europe by Jurassic species. *Limea duplicata* Sowerby, recorded from the Jurassic of east Greenland,[3] is the only species in Mesozoic deposits on the American side of the Atlantic. *Limea solida*

[3] Bernhard Lundgren: Anmärkningar om några Jurafossil från Kap Stewart i Ost-Grönland. Meddeleeser om Grönland, vol. 19, 1895, pp. 189-214, pls. 3-5.

Dall—originally described from the Bowden formation (middle Miocene) of Jamaica, and also occurring in the Gurabo formation (middle Miocene) of the Dominican Republic and the Gatun formation (middle Miocene) of Costa Rica—is the only American Tertiary species. As this genus has a long history, it probably was living along the American side of the Atlantic during Cretaceous and Tertiary time. None of the genera in the preceding list are known in Mesozoic deposits. Therefore it is not likely that the record for many of them is defective, as it probably is for *Limea*.

The same test to determine possible Miocene means of migration can not be applied to the borders of the south Atlantic because of the scarcity there of marine Miocene deposits. The Miocene Patagonian beds of Patagonia[4] carry an austral fauna different in most features from the tropical faunas of the West Indies and the subtropical faunas of the Mediterranean region. It seems reasonable to believe that during Miocene time there were climatic zoogeographic provinces south of the equator similar to those north of the equator.

The possibility of migration from Mediterranean to West Indian waters, or from West Indian to Mediterranean, by way of the Pacific seems to be excluded by the evidence indicating that the Tertiary Mediterranean Sea and Indian Ocean were separated after Eocene time.[5] Besides, the Miocene faunas of the Pacific States of the United States have a different aspect.

Virtually all the mollusks listed on page — are shallow-water dwellers. It is not likely that any of them had a free-swimming larval stage long enough to permit them to cross the tropical waters of the Atlantic. The present Atlantic would be as effective a barrier to their migration from one side to the other as a land barrier. A series of shoal-water banks or islands across the southern border of the north Atlantic, spaced at intervals within the cruising range of the larvæ, would afford the only means of migration for these tropical and subtropical shallow-water mollusks.

The similarity in the West Indian and Mediterranean Helvetian faunas is particularly striking in the following families: Ledidæ, Malletiidæ, Arcidæ, Lucinidæ, Ranellidæ, Septidæ (= Tritonidæ), Olividæ, Mitridæ, Marginellidæ, Columbellidæ, Cassidæ, Terebridæ, and Conidæ. Other families—especially the Cardiidæ, Veneridæ, Tellinidæ, Mactridæ,

[4] A. E. Ortmann: Tertiary invertebrates. Reports of the Princeton University expeditions to Patagonia, 1896-1899, vol. 4, 1902, pt. 2, pp. 45-332, pls. 11-39 (see pp. 286-303, 319-324).

[5] See discussion by T. W. Vaughan: The basis of the correlation of post-Cretaceous formations of the Pacific region. Bernice P. Bishop Museum Special Pub. 7, 1921, pp. 866-873.

Rissoidæ, and Trochidæ—have an unusually large percentage of provincial genera on both sides of the Atlantic. This difference may be due to the length of the free-swimming larval stage or to its absence, but it has not been possible to assemble the known information about the larval development of the living genera.

Morphology of the North Atlantic and its Borders

The present morphology of the north Atlantic fails to support the supposition that there were any Tertiary shoal-water banks or islands stretching across its southern part. Its major features comprise two broad northward-trending S-shaped troughs, separated by an almost median, narrow, S-shaped ridge. The Azores are peaks on this ridge rising above the surface of the water. The alignment of the Azores in parallel bands trending north-northwest is the only feature suggesting a geographic pattern out of harmony with the present arrangement.

The alignment of the marine Mesozoic and Tertiary deposits on the American side of the Atlantic suggests that this part of the basin is very old; but on the European and African side there are no bands of Mesozoic and Tertiary marine deposits parallel to the present coast, excepting small areas in Spain and Portugal. The marine Mesozoic and Tertiary deposits on this side of the Atlantic are limited to embayments between mountain cores that strike into the sea. In Morocco the Tertiary folds of the Atlas Mountains plunge into the Atlantic, striking west-southwestward toward the Canaries.[6] According to Termier,[7] a band of Alpine folds emerges from under the overthrust sheets of the Sierra Nevada in southern Spain and continues westward to Cape Saint Vincent, where it is abruptly cut off by the sea. The projected strike extends toward the southern islands of the Azores.

So far as its eastern border is concerned, the evidence indicates that the present northward-trending features of the north Atlantic mask an earlier morphology.

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[6] Louis Gentil: Les mouvements tertiaires dans le Haut-Atlas marocain. Compt. Rend., vol. 150, 1910, pp. 1465-1468.

Les grandes lignes du relief marocain. Revue générale des sciences pures and appliquées, vol. 22, 1911, pp. 486-493, 2 figs. (see p. 491).

Le Maroc physique, 319 pp., 4 figs., Paris, 1912 (see pp. 44, 100-102).

[7] Pierre Termier: L'Atlantide. Revue Scientifique, Année 51, sem. 1, no. 2, pp. 33-41, Jan. 11, 1913 (see p. 39); also published in Institut Océanographique Bull. 256, 22 pp., Jan. 20, 1913; A la gloire de la terre, pp. 117-146, Paris, 1922; English translation published in Smithsonian Inst. Annual Rept. 1915, 1916, pp. 219-234.

Inferred Tertiary History

The faunal evidence here presented, based on a detailed comparison of the West Indian and Mediterranean Miocene mollusks, indicates that a series of shoal-water banks or islands extended across the southern part of the north Atlantic during Miocene time. These supposed banks or islands have completely disappeared and no trace of them is visible in the features of the present Atlantic, except, possibly, in the islands in its eastern part. According to the faunal evidence, their disappearance is of late Miocene or Pliocene age, as after Helvetian time the similarity between the West Indian and Mediterranean mollusks decreases. The Pliocene faunas of the Mediterranean region have a clearly discernible but diminished West Indian aspect. The extinction in European and African waters of so many genera that lived on both sides of the Atlantic during Miocene and even Pliocene time and their survival in West Indian waters is a mystery, as it is not entirely due to climatic changes. It is comparable to the extinction in the West Indies and their survival in the Pacific of many genera that lived in West Indian waters during Miocene time. The subtropical Miocene and Pliocene Mediterranean fauna was replaced during Quaternary time by a temperate fauna coming from the north Atlantic. Even in Quaternary time a subtropical fauna at times lived in the Mediterranean, especially during the Tyrrhenian stage. This subtropical fauna finally was exterminated in the Mediterranean. A similar fauna, in some features resembling the living West Indian fauna and harboring some essentially Tertiary genera, such as *Pseudoliva* and *Protoma*, is now living along the Atlantic coast of northern Africa. The similarity between the living West Indian and west African faunas probably is due to a survival in tropical west African waters of some genera that formerly lived in the Miocene and Pliocene Mediterranean Sea.

The only marine Miocene deposits in the north Atlantic above sealevel are in the Azores[8] and Canary Islands.[9] The fauna of these deposits, which probably are of Helvetian age, is the westward extension of the Mediterranean Miocene fauna. The deposits in the island of Porto Santo of the Azores archipelago carry the only described Miocene *Pseudoliva*.

[8] Karl Mayer: Paläontoligische Verhältnisse, in G. Hartung, Geologische Beschreibung der Inseln Madeira und Porto Santo, Leipzig, 1864, pp. 183-298, 8 pls.

Cotter, J. C. Berkeley: Noticia de algunas fosseis terciarios do Archipelago da Madeira: Noticia de algunas fosseis terciarios da Ilha de Santa Maria no Archipelago dos Açores. Commissão dos Trabalhos Geologicas de Portugal Communicações, vol. 2, 1892, pp. 232-287.

[9] A. Rothpletz and V. Simonelli: Die marinen Ablagerungen auf Gran Canaria. Deutsch. Geol. Gesell. Zeitschr., vol. 42, 1890, pp. 677-736, pls. 35, 36.

This genus is represented by several species in the Eocene deposits of Europe and America, but is now living only on the west African coast.

The data on which isostasy is based precludes the possibility of the supposed north Atlantic Miocene banks or islands being transformed into ocean depths without an increase in their density. Overloading by the pouring out of basic lavas may account for the increase in density, or there may be unsuspected changes in the density of the earth crust.[10]

Areas of plateau basalts with which plant-bearing beds are interbedded are widely distributed in the northern part of the north Atlantic. Washington[11] recently has called these basalts the Thulean basalts. They extend from northern Ireland and western Scotland northwestward and northward to Iceland, Greenland, and Spitzbergen. The plant-bearing beds are principally of Eocene age. In all this region there are no marine Tertiary deposits except in Greenland and Spitzbergen, where the sea may have come in from the Pacific. It is commonly inferred that these areas of Thulean basalts are remnants of a former extensive landmass stretching across the north Atlantic. The disappearance of the greater part of this landmass may have been due to the rise of the basic magmas.

The disappearance of the supposed shoal-water banks or islands in the southern part of the north Atlantic may have been similar to the events in the northern part; but no remnants are left in the southern part, except possibly in the Azores and in the islands (Madeira, Canaries, Cape Verde) near the eastern border of the ocean.

The Tertiary age of part of the north Atlantic basin has been supported by many writers, and its advocates claim the support of different kinds of evidence. Suess[12] outlined the growth of the basin by successive enlargements during Mesozoic and Tertiary time. The evidence was based on the tectonic features of the eastern border of the basin and on the Mediterranean aspect of the late Cretaceous and early Tertiary marine fossils of the West Indies. The same evidence led de Launey,[13] de Lapparent,[14] Haug,[15] Gentil,[16] and Termier[17] to support this belief.

[10] J. Barrell: The nature and bearing of isostasy. Amer. Jour. Sci., series 4, vol. 48, 1919, pp. 281-290 (see p. 288).

[11] H. S. Washington: Deccan traps and other plateau basalts. Bull. Geol. Soc. America, vol. 33, 1922, pp. 765-804, 2 figs. (see p. 780).

[12] Eduard Suess: La face de la terre, vol. 1, 1897, pp. 362-365, 369-377; vol. 2, 1900, pp. 490, 544.

[13] L. de Launey: La science géologique, 1905, pp. 255-256.
Où en est la géologie, Paris, 1921 (?), pp. 71-94.

[14] A. de Lapparent: Traité de géologie, 1906, p. 1580.

[15] Emile Haug: Les géosynclinaux et les aires continentales. Soc. géol. France Bull., ser. 3, vol. 28, 1900, pp. 617-711, 3 figs. (see pp. 640-641).
Traité de géologie, 1907-11, pp. 166-170, 1558-1562, 1732.

Germain[18] believes that the fauna and flora of the islands in the eastern part of the north Atlantic can be explained only by supposing that the islands formerly were part of a land area. Termier and Germain even have contended that the Atlantis of Plato was the last remnant of the Tertiary north Atlantic lands disappearing within the memory of early man. Germain[19] and others have attempted to outline the Tertiary history of the lost north Atlantic lands with perhaps an unwarranted precision.

It is difficult to accept the extreme views advocated by Haug and others as to the position of the Mesozoic and Tertiary continents and seas. The question immediately arises as to the source of the water now filling the oceanic basins. Such a volume of water could hardly have come from volcanic emanations in so short a time, as has been suggested. This test should also be applied to the inferred history of the north Atlantic. So far as the West Indies and Central America are concerned, the withdrawal of water to fill the enlarged north Atlantic basin might account for the scarcity of marine upper Miocene and Pliocene deposits; but it is probably impossible to eliminate the effects of other events in attempting to apply this test to any part of the earth. Guppy[20] long ago was impressed by the similarity of the West Indian and Mediterranean Miocene mollusks and advocated the same means of direct migration between the two regions. Gregory[21] reached the same conclusion from a

[18] Louis Gentil: Le Maroc physique, 1912, pp. 103-124.

[17] Pierre Termier: L'Atlantide (see footnote 7, p. —). Les océans à travers les âges. Institut Océanographique Bull. 365, March, 1920, 20 pp.; also published in Revue Scientifique, Année 53, no. 9, May, 1920, pp. 257-266; A la gloire de la terre, Paris, 1922, pp. 357-388.

[18] Louis Germain: Sur l'Atlantide. Compt. Rend., vol. 153, 1911, pp. 1035-1037.

[19] Louis Germaine, Louis Joubin, and Ed. Le Danois: Une esquisse du passé de l'Atlantique-Nord. La Géographie, vol. 40, 1923, pp. 281-293, 4 figs.

[20] R. J. L. Guppy: On the Tertiary Mollusca of Jamaica. Geol. Soc. London Quart. Jour., vol. 22, 1866, pp. 281-295, pls. 16-18 (see pp. 150-152).

On the relations of the Tertiary formations of the West Indies. Geol. Soc. London Quart. Jour., vol. 22, 1866, pp. 570-590, pl. 26 (see pp. 584-590).

On the Tertiary fossils of the West Indies, with especial reference to the classification of the Kainozoic rocks of Trinidad. Sci. Assoc. Trinidad Proc., pt. 3, 1867, pp. 145-176 (see pp. 150-152); republished in Bull. Amer. Paleontology, vol. 8, 1921, pp. 172-203.

Notes on West Indian geology, with remarks on the existence of an Atlantis in the early Tertiary period, and descriptions of some new fossils from the Caribbean Miocene. Geol. Mag., vol. 4, 1867, pp. 486-501, 6 text figs.

On the West Indian Tertiary fossils. Geol. Mag., decade 2, vol. 1, 1874, pp. 404-411, 433-446, pls. 16-18 (see p. 405).

The geological connexions [sic] of the Caribbean region. Canadian Inst. Trans., vol. 8, 1909, pp. 373-391, map.

[21] J. W. Gregory: The relations of the American and European echinoid faunas. Bull. Geol. Soc. America, vol. 3, 1892, pp. 101-108 (see pp. 105-106).

Contributions to the palæontology and physical geology of the West Indies. Geol. Soc. London Quart. Jour., vol. 51, 1895, pp. 255-312, pl. 11, 2 text figs. (see pp. 305-307).

study of the West Indian and Mediterranean Miocene echinoids. Other tropical marine Tertiary fossils are remarkably similar on the two sides of the Atlantic. Vaughan[22] has based the correlation of the West Indian middle Oligocene deposits on the similarity of their corals to species in the Rupelian of the Venetian basin of Italy. Trechmann[23] has recently traced the similarity of the mollusks from the Yellow limestone (middle Eocene) of Jamaica to Eocene species from Senegal. The present paper is based on a more detailed comparison of the Miocene mollusks than had heretofore been attempted.

[22] T. W. Vaughan: Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent coral reefs. U. S. Nat. Mus. Bull. 103, 1919, pp. 189-524, pls. 68-152, text figs. 4-25 (see pp. 202-203).

[23] C. T. Trechmann: The Yellow limestone of Jamaica and its Mollusca. Geol. Mag., vol. 60, 1923, pp. 337-367, pls. 14-18 (see p. 346).

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BAUXITE ASSOCIATED WITH SIDERITE[1]

BY ERNEST F. BURCHARD

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DISCOVERY OF NEW BAUXITE FIELD

A new bauxite field in northeastern Mississippi was discovered in an interesting way by J. W. Adams, of Tuscumbia, Alabama, in 1921. In a search for bauxite, Adams began a study of the literature of the geology of Mississippi, and in a report published by State Geologist Hilgard in 1860 he found the following excellent pen picture of bauxite in a description of the "Orange Sand."[2]

"A singular rock belonging to this formation, and much resembling a true puddingstone, is found in a few localities in west Tippah and east Lafayette counties, on the territory of the Lignitic Tertiary. (For example, section 1, township 5, range 2 east, Tippah County; section 33, township 9, range 1 west, Lafayette County.) It consists of a ferruginous and somewhat sandy cement, in which are imbedded numerous rounded concretions of a pisolithic structure, formed of concentric layers of a siliceous material, more or less ferruginous, and in some almost white, the largest being about three-fourths inch in diameter."

[1] Manuscript received by the Secretary of the Society January 14, 1924.
Published with the permission of the Director, U. S. Geological Survey.

[2] E. W. Hilgard: Report on the geology and agriculture of the State of Mississippi. Jackson, Mississippi, 1860, p. 14.

Hilgard evidently had not recognized the material as bauxite; in fact, bauxite seems not to have been known to occur in the United States until recognized in Georgia and Arkansas in 1887. Attracted by Hilgard's description, Adams at once examined the deposit in Tippah County and took samples that on analysis proved to be good bauxite. Thus encouraged and guided by the geologic relations which he had observed, Adams made a reconnaissance through northeastern Mississippi which led to finding bauxite in 10 counties.

More than 60 years elapsed between the publication of Hilgard's description and the utilization of the information. In that interval many geologists had been over the same ground in quest of underground water, clays, iron ore, and petroleum, and presumably had read the report, but it fell to the lot of a non-technical, but keen and persevering, prospector to interpret the facts and to bring to light this interesting resource. Geologists may, however, console themselves in the fact that the note as published by Hilgard was clear and accurate, and that it eventually pointed the way to a valuable discovery.

The Bauxite Deposits

Distribution and topographic relations

The bauxite is distributed in groups of small separate deposits in a belt 3 to 5 miles wide describing an arc from north to southeast about 150 miles long, corresponding to the outcrop of the associated formations throughout the northeastern quarter of Mississippi, crossing portions of Tippah, Benton, Union, Pontotoc, Calhoun, Webster, Oktibbeha, Winston, Noxubee, and Kemper counties. Most of the deposits are 5 to 10 or more miles from a railroad and separated from it by "Flatwoods" country, underlain by deep, sticky clay, the unsurfaced roads over which are practically impassable for vehicles in wet weather and are hard and rutty in dry seasons.

The surface of northeastern Mississippi represents a moderately dissected plateau which slopes very gently toward the southwest. The former plateau is represented by the interstream ridges and gently rolling or broken uplands. Many deep, narrow ravines open from the uplands into the valleys, and in these localities the hill slopes are steep. The streams are fed by springs and by surface run-off, which is gathered by innumerable small branches that flow only in wet weather. The surface relief ranges from about 175 feet above sealevel near Macon, Noxubee County, to nearly 700 feet above sealevel on the highest points near the north border of the State, but in general the higher ridges are at alti-

tudes of 450 to 600 feet, with the larger streams 200 to 250 feet lower, giving considerable relief for a region developed on poorly consolidated rocks.

The bauxite deposits are found generally on the crests of hills and ridges or high on the slopes and on high terraces, but a few instances were noted of the occurrence of bauxitic material, exposed by small streams, perhaps 50 feet lower than other points containing bauxite in the vicinity. The altitude of the bauxite deposits ranges from 400 to 500 feet above sealevel and they lie generally 50 to 100 feet above local drainage. Their topographic position has been determined by the superior hardness of the rock bauxite, which has resisted erosion longer than the sands and clays of which the associated formations are largely composed. The hills which contain the bauxite are on the western border of the Flatwoods area, the topographic features of which are due to the character of the underlying formation, the Porters Creek clay.

STRATIGRAPHIC RELATIONS

General statement.—Stratigraphically the bauxite is in the lower part of the Ackerman formation, the lowest formation of the Wilcox group of the Eocene. Underlying the Ackerman is the Porters Creek clay of the Midway group, also of Eocene age. It is believed that the Midway-Wilcox contact is unconformable. The formations dip gently toward the southwest, 15 to 25 feet to the mile in the northern part of the field, and do not appear to have been faulted. The formations most closely associated with the bauxite, the Porters Creek clay and the Ackerman formation, will be described briefly.

Porters Creek clay.—The Porters Creek, or "Flatwoods," clay of the Midway group, which lies below the beds containing the bauxite, consists of 150 to 200 feet of very fine-grained gray joint clay, slightly lignitic. Dr. E. N. Lowe, State Geologist of Mississippi, considers that it was laid down in fresh water.[3] Petrographic examination by C. S. Ross, of the United States Geological Survey, shows that this clay contains an appreciable proportion of bentonitic material, possibly related to leverrierite (?). When immersed in water, the clay slacks slowly and on drying, it breaks into rounded nodular lumps and conchoidal spalls. The surface of this clay generally exhibits a flat, even topography and is forested with inferior grades of oak and pine.

Analysis number I, by J. G. Fairchild, of the United States Geological Survey, is the only one available of the Porters Creek clay. The speci-

[3] E. N. Lowe: Mississippi, its geology, geography, soil, and mineral resources. Bulletin Mississippi State Geological Survey, no. 14, 1919, p. 64.

men was taken from about 25 feet below a deposit of gravel bauxite one mile northwest of Blue Mountain, Tippah County, Mississippi. The resemblance in composition to bentonite, analyses of which are given under II and III and IV, is of interest.

Analysis of Porters Creek Clay from Mississippi and of Bentonite from Tennessee and Wyoming

	I	II	III	IV
Silica (SiO_2)	60.68	56.80	63.25	59.78
Alumina (Al_2O_3)	15.66	17.01	12.63	15.10
Ferric oxide (Fe_2O_3)	6.40	2.87	3.70	2.40
Ferrous oxide (FeO)	none	....	....	....
Titanium dioxide (TiO_2)	1.00	0.12	....	....
Manganous oxide (MnO)	trace (?)	....	....	....
Magnesium oxide (MgO)	1.75	4.26	3.97	4.14
Calcium oxide (CaO)	0.29	4.40	4.12	0.73
Sodium oxide (Na_2O)	....	(?) 14.54	....	....
Potassium oxide (K_2O)	....		3.55	....
Sulphur trioxide (SO_3)	....		1.58	....
Moisture (H_2O—)	5.56	....	....	....
Water (H_2O+)	6.18	....	6.91	16.26
Carbon dioxide (CO_2)	none	....	....	....
	97.52	100.00	99.71	98.41

I. Porters Creek clay, Blue Mountain, Mississippi.

II. Bentonite from Bragg's quarry, near Chattanooga, Tennessee. W. A. Nelson: Appalachian bauxite deposits. Bulletin of the Geological Society of America, volume 34, September 30, 1923, page 537.

III. Bentonite from Newcastle, Wyoming. United States Geological Survey Bulletin 285, 1906, page 446.

IV. Bentonite from Peach Creek, Wyoming. United States Geological Survey Bulletin 260, 1905, page 560.

In the northern part of Mississippi beds of sand, sandstone, and clay, reaching a maximum thickness of 100 feet in Tippah County, lie at the top of the Porters Creek clay and have been termed the Tippah sandstone member. The sandstones are gray to greenish gray in color, becoming yellowish on weathering; they are fossiliferous and are speckled with grains of glauconite. The superior resistance to erosion possessed by these beds has produced a hilly topography along the west border of the Flatwoods area, such as the eminence known as Blue Mountain, an east-facing escarpment in Porters Creek clay capped by beds of the Tippah sandstone member. These beds have been recognized in Hardeman County, Tennessee, but probably thin and disappear toward the south, as they have not attracted attention south of Tippah County.

Ackerman formation.—The Ackerman formation, which contains the bauxite deposits, consists of 500 to 600 feet of gray, more or less lignitic clay, lignite, and variegated sand. In the basal portion of the formation are irregular shaped bodies of interbedded bauxite and light-colored clay. The clay contains too much fine-grained silica sand to be regarded as kaolin, but is mixed with varying proportions of bauxite. Associated with the bauxite and elsewhere at two or three horizons in the lower part of the formation are lenticular masses of siderite 6 to 20 inches thick. This iron carbonate is light gray where fresh, but alters to limonite in concentric shells on the surface. It is of dense, fine-grained and homogeneous texture, and is tough and extremely resistant to the blows of a hammer. At Winborn, Benton County, a deposit of iron ore, mainly limonite altered from siderite, was mined from an open cut and pig iron was made from it in a small charcoal blast furnace in 1914.

The Ackerman beds are regarded by Lowe[4] as having been laid down in fresh water, a large part of them having been deposited in peat swamps, as indicated by the character of the fossil leaves and tree trunks associated with the lignite, and Berry[5] regards the beds of iron carbonate as furnishing "striking evidence of the palustrine character of the early Wilcox, the low surface of the Wilcox mainland, the absence of terrigenous materials in the Wilcox lagoons at this time, and the highly ferruginous character of the run-off." There is physical evidence in Mississippi of an unconformity between the Ackerman and the underlying Porters Creek clay in the abrupt change and widely different character of the sediments, and C. W. Cooke[6] finds faunal indications of an unconformity. Berry[7] notes an erosional unconformity between the Midway and Wilcox near Fort Gaines, Georgia, where numerous pothole-like depressions in the Midway as much as 20 feet deep are filled with Wilcox deposits, and cites other evidence of erosional unconformities along the Rio Grande in Texas, but he considers that the most convincing evidence has been brought to light through a study of the fossil floras. As is indicated later, it is of importance to correctly interpret the geologic history of the early Wilcox in order to account for the origin of the bauxite and siderite.

The topography of the Ackerman formation area is more or less rolling and hilly, becoming rougher toward the west, where it is overlain by the Holly Springs sand.

[4] E. N. Lowe: Op. cit., p. 67.

[5] E. W. Berry: The lower Eocene floras of southeastern North America. U. S. Geol. Survey Prof. Paper 91, 1916, pp. 43-44.

[6] Personal communication.

[7] E. W. Berry: Erosion intervals in the Eocene of the Mississippi embayment. U. S. Geol. Survey Prof. Paper 95, 1916, p. 76.

FORM OF DEPOSITS

About 60 deposits, most of them bauxite, the rest bauxitic clay or bauxitic limonite, were examined by the writer in northeastern Mississippi in the summer of 1923, and there are reported to be many deposits that were not visited. These deposits ranged in size from roadside outcrops a few inches in thickness and a few feet in length to bodies proved by prospecting to be 10 to 15 feet thick and to occupy an area of several acres. Many of the deposits are in groups so situated topographically as to suggest that they were originally parts of a single larger body that later had been dissected and greatly reduced in size by erosion.

None of the deposits has been mined, and until they are mined out their exact form will not be certainly known, but prospecting by digging pits and drilling holes has outlined fairly well the general form of a large number of them. A few consist of a fairly even ledge of rock bauxite capping the flat top of a hill, and others consist of more or less disintegrated rock bauxite in a similar position. Many deposits appear to occupy terraces slightly below the highest topographic level and to have been exposed by erosion on the escarpments or steep upper slopes of the hills. Testing indicates that these deposits on terraces have irregular outlines, vertically as well as laterally, and that they do not extend far into the hills. Where hard bauxite is found to occupy knobs or ridges its presence has influenced the local topographic forms.

In a general way the original form of the bauxite deposits may have been lenticular, such as would have been assumed by deposits of chemical-sedimentary origin in swampy depressions. In places there is suggestion of the action of spring waters, but this is believed to have been subsequent to the formation of the main mass of bauxitic material. In vertical section the deposits consist of alternate layers of bauxite and clay, the latter varying from a more or less bauxitic state to clay practically free from bauxite and admixed with sand. Many detailed sections were found to vary greatly even for test pits that are not far apart. The hard bauxite is found usually at the surface, either at the top of the deposit or on the outcrop at the brow and on the slope of the hills. The induration may have been caused by a secondary process of "case-hardening," due in part to deposition of iron carbonate by percolating waters and the subsequent alteration of the iron carbonate to limonite, for it is found that the harder bauxite is generally more ferruginous than the softer form.

In the prospect pits and drill-holes, which ranged in depth from 4.3 feet to 46 feet, the total thickness of the layers of bauxite and bauxitic clay encountered ranged from about 2 feet to 15.7 feet. The areal extent of the principal deposits, as indicated by prospecting, ranges from about

.6 acre to more than 9 acres, but it is not certain that bauxite is present below the whole of such large areas, because prospecting has not been sufficiently intensive. The structure of the deposits seems to be that of many overlapping lenses of bauxite and clay, and some of these exhibit more or less gradation from one into the other.

CHARACTER

The Mississippi bauxite is not at all uniform in physical or chemical character, and in this respect it is similar to most other American bauxite. The two most diverse types of material found in Mississippi are the hard, or rock bauxite, and the soft, claylike form. The specific gravity in lump form of four specimens from this field ranges from 1.585 in claylike material to 2.730 in rocklike, pisolitic material cemented by siderite. A large pisolite of fairly pure bauxite, containing 59.58 per cent of alumina, 2.78 per cent silica, 1.72 per cent ferric oxide, 3.60 per cent of titanium dioxide, and 31.98 per cent H_2O+, showed a specific gravity of 2.050.

The rock bauxite consists of rounded, concretion-like bodies, termed pisolites, set in a finer-grained matrix or cementing medium. The pisolites range in size from smaller than the head of a pin to 1½ inches in diameter. They vary in color from nearly white to yellow, brown, and reddish tints, and are composed of fine-grained, non-crystalline, but strongly compacted, earthy material. Polished sections show the larger pisolites to be made up of smaller granular and concretionary bodies. The hardness of typical pisolites is between 3 and 4 in the Mohr scale, or a little greater than that of calcite, but the pisolites that contain considerable iron oxide are a little harder. The matrix, where ferruginous, may be as hard as the pisolites, but where free from iron it is softer. In the Mississippi field the pisolites usually contain a higher percentage of alumina than the cementing matrix, and therefore where a deposit contains a large proportion of pisolitic rock bauxite it may be expected to carry relatively good values in alumina. On the other hand, the harder material is likely to carry a high percentage of iron oxide, which will offset to some extent the value of the bauxite for certain purposes. The pisolitic material is similar in most respects to that type of bauxite in other American fields, but in the softer material there appears to be more silica and impure clay and less kaolin present than in the Georgia Coastal Plain deposits. The softer, claylike material is less pisolitic than the rock bauxite, and some that is high in bauxite may show no pisolites at all. Pseudo-pisolites occur locally in some clays and sands that do not contain bauxite, and so the presence of these small concretionary bodies

in the softer material is not always a certain evidence of the presence of bauxite.

The rock bauxite outcrops on the crests or upper slopes of hills and in places extends for a short distance into the hills under a cover of a few feet of soil. It is also found as boulders broken from the rock ledges or scattered about on wooded hills and in hillside fields, and in places it has so disintegrated as to leave only loose gravel and coarse sand, or "buckshot" ore. The soft bauxite and bauxitic clay are found below a capping of rock bauxite or of soil, sand, and other unconsolidated material, and as layers alternating with material that contains but little bauxite.

Considerable iron is present in the rock bauxite, as has been noted above, and the feature of interest in this connection is that in much of the material the iron is present in the mineral siderite, which in fresh specimens forms a brilliantly crystalline matrix, but in most of the material the siderite has altered to limonite. Small cavities were noted lined with rhombohedral crystals of siderite 2 or 3 millimeters in length, exhibiting curved faces. Dense, fine-grained siderite occurs in lenticular masses below and interbedded with the bauxite, and this association, as well as in the matrix of the bauxite, is unusual for bauxite of the Coastal Plain, so far as the writer has been able to ascertain, but Mead[8] has noted secondary siderite in the bauxite near Little Rock, Arkansas.

Bauxite is of commercial value because it consists of a mixture of hydrated oxides of aluminum from which the metal aluminum or its salts are obtained. There are two other substances closely related to bauxite, both of them hydrated oxides of aluminum, that have been identified in crystalline form and found to contain definite proportions of alumina and water, namely, diaspore ($Al_2O_3.H_2O$) and gibbsite ($Al_2O_3.3H_2O$), and it was formerly considered that bauxite could be represented by the formula $Al_2O_3.2H_2O$, thus placing it intermediate between the two other hydrates. However, the definite mineral corresponding to the formula of aluminum dihydrate seems not to have been identified and its existence is doubtful. In view of these conditions, it seems that the term bauxite may properly be applied to an amorphous mixture of hydrates of alumina containing percentages of water intermediate between that of diaspore and gibbsite. Clarke finds it sometimes near one and sometimes near the other of these minerals.[9]

The composition of the Mississippi bauxite seems to corroborate

[8] W. J. Mead: Occurrence and origin of the bauxite deposits of Arkansas. Economic Geology, vol. 10, no. 1, January, 1915, p. 43.

[9] F. W. Clarke: The data of geochemistry. U. S. Geol. Survey Bull. 616, 1916, p. 498.

these relations, for if the loss on ignition be considered as entirely water and be applied to the requirements of the ferric oxide as limonite ($2Fe_2O_3.3H_2O$), and of the alumina as diaspore ($Al_2O_3.H_2O$) or as gibbsite ($Al_2O_3.3H_2O$), it is found that the quantity is higher than would be required for diaspore and also generally higher than would be required by a dihydrate, if there were such a compound, and slightly lower than required by gibbsite, although inclining toward the latter. Petrographic examination by C. S. Ross shows that the substance of both pisolites and matrix is mainly amorphous, but he noted a few traces of crystalline material that included very small quantities of diaspore and gibbsite. The indices of refraction of the amorphous material varied between that of diaspore and that of gibbsite. The natural inference is that this variation indicates an amorphous mixture of these two hydrates of alumina.

Inspection of many analyses shows that hydrates of alumina are seldom found in a pure enough state to yield the maximum percentages of alumina. In the Mississippi deposits the commonly associated minerals are clay, sand, siderite, limonite, and various silicates and oxides, among which the oxide of titanium is almost always present. In commercial chemical analyses the determinations commonly made are those of alumina (Al_2O_3), ferric oxide (Fe_2O_3), silica (SiO_2), titanium dioxide (TiO_2), combined water (H_2O+), and moisture (H_2O-). One hundred or more analyses made by Dr. W. F. Hand, State chemist of Mississippi at the Agricultural College laboratories, and a few by J. G. Fairchild, of the United States Geological Survey, indicate that a large proportion of the Mississippi bauxite in its natural state contains so much ferric oxide and silica that it is of low to medium grade as compared with deposits that are now being mined in Arkansas, Alabama, Georgia, and in foreign countries. The following tabular summary of ranges in composition brings out these relations:

Range in Composition of Bauxite

Locality	Al_2O_3 Per cent		Fe_2O_3 Per cent		SiO_2 Per cent		TiO_2 Per cent		H_2O Per cent	
	Range	Bulk	Range	Bulk	Range	Bulk	Range	Bulk	Range	Bulk
Northeast Mississippi[10]	25–60	35–45	0–40	5–35	3–40	10–30	0.5–3.6	1.5–2.5	11–32	15–25
Georgia (Coastal Plain)[11]	34–62	46–58	0.5–34	1–5	1.2–32	10–20	0.23–3.08	1.6–2.4	14–33	23–30
Georgia (Paleozoic)[12]	51–67.5	53–59	0–14	1–3	0.6–12	2.7–4.8	0–8.8	2.4–4.2	24–33	28.4–31.5
Alabama[12] (Paleozoic)	41–62	.....	1.20–23	.....	0.4–9	.....	3.12–3.40	.....	20–32	.....
Tennessee[13], Missionary Ridge	55–58	.....	1.10–1.38	.....	11–13	.....	.....	.....	29–30.3	.....
Arkansas[12]	52–62	52–53	1.7–22	4–10	2–17	4–10	3.5–4	3.5	17–30	29–30
Arkansas[14]	46–60	.....	1.6–4.8	.....	5.5–24.8	.....	1.3–2.8	.....	22.9–30.7	.....
France[12]	60–82	.....	0.10–25	.....	2–3	.....	.....	.....	12–14	.....
France[15] (red variety)	30–33	.....	35–49	.....	0–2	.....	0–1.6	.....	8.6–22	.....
France[15] (white variety)	55–77	.....	0.10–25	.....	0.30–4.8	.....	3.1–4	.....	11–16	.....
Germany[12]	46–76	.....	6–19	.....	4–11	.....	.....	.....	26–32	.....

[10] W. F. Hand, Mississippi Agricultural and Mechanical College, and J. G. Fairchild, U. S. Geological Survey, Analysts.
[11] From H. K. Shearer: Report on the bauxite and fuller's earth of the Coastal Plain of Georgia. Geol. Survey of Georgia, Bull. No. 31, 1917.
[12] From T. L. Watson: Preliminary report on the bauxite deposits of Georgia. Geol. Survey of Georgia, Bull. No. 11, 1904.
[13] W. C. Phalen: Bauxite and aluminum in 1914. Mineral Resources U. S. for 1914, part 1, 1915, p. 187.
[14] W. J. Mead: Op. cit., p. 50. Analyses of a series of 14 samples from 3 feet to 31 feet below the surface in the same test pit.
[15] W. C. Phalen: Op. cit. for 1910, part 1, 1911, p. 716.

SUGGESTIONS AS TO GENESIS

Geologic relations of this bauxite of possible significance are that it occurs in a formation that was evidently laid down in fresh water, largely in peat swamps, and that this formation overlaps a thick clay which petrographic examination and chemical analysis have shown to contain a considerable proportion of bentonitic material. Below the clay and outcropping to the east of it are formations containing a great deal of glauconite. These relations offer suggestions as to the deposition of both the siderite and the bauxite. The glauconite is a possible and adequate source of the iron. Waters containing organic acids acting on glauconite would produce solutions of iron salts, from which the iron might be precipitated as iron carbonate through the influence of carbonic acid and possibly bacterial organisms. Iron carbonate ore, apparently derived from glauconite, occurs in rocks of Eocene age in northeastern Texas.[16] Laboratory studies by Nelson[17] lead to the conclusion that bentonitic clay will readily yield alumina to ground waters containing small quantities of sulphuric acid, and that swamp or surface waters containing tannic acid will precipitate the alumina. Thus it is possible that streams flowing from the Cretaceous and early Eocene land areas on the east bore glauconitic and bentonitic material in a finely divided state, as well as iron and aluminum salts in solution, into the waters of the Ackerman swamps, which, being charged with organic acids, produced favorable conditions for the precipitation of iron carbonate and aluminum hydroxide. Nelson indicates that similar principles may have controlled the deposition of bauxite near Chattanooga, Tennessee, where alumina, derived from bentonite, is believed to have been precipitated through the influence of organic acids in or near peat swamps. He considers that the formation of the bauxite in East Tennessee took place in early Pleistocene time, but Watson[18] considered the age of the bauxite deposits of the Paleozoic area of Alabama-Georgia, which may, perhaps, be correlated with those near Chattanooga, to be late Eocene, which is more nearly contemporaneous with those of northeastern Mississippi. The bentonitic source of the alumina in East Tennessee, however, is probably of Ordovician (Lowville) age, although the rocks on which the bauxite rests are even older, and Nelson's explanation of the origin of the East Tennessee bauxite requires faulted structure and upward-moving ground water.

[16] Ernest F. Burchard: Iron ore in Cass, Marion, Morris, and Cherokee counties, Texas. U. S. Geol. Survey Bull. 620, 1915, pp. 69-109.

[17] Wilbur A. Nelson: Appalachian bauxite deposits. Bull. Geol. Soc. America, vol. 34, September 30, 1923, pp. 525-539.

[18] T. L. Watson: Preliminary report on the bauxitte deposits of Georgia. Good Survey of Georgia, Bull. 11, 1904, p. 130.

The bauxite in northeastern Mississippi seems to have been formed under much simpler conditions of deposition, similar, perhaps, to those under which deposits of bog iron ore are believed to have originated. There appears to be no good evidence that these bauxite deposits originated through agencies of subaerial weathering and residual accumulation, although the possibility of the formation of some of the material through the alteration of water-laid clays should be considered.

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FRANKLIN MOUNTAINS[1]

BY MERTON YARWOOD WILLIAMS

(*Read before the Society December 28, 1923*)

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LOCATION AND EXTENT

Franklin Mountains lie east of Mackenzie River and extend from Willow Lake River, latitude 62° 45′ north, northward to an unknown distance beyond Great Bear River, probably to latitude 65° 30′ north. At their southern extension they flank Mackenzie River, but northward they are in general from 4 to 6 miles to the east, and for 45 miles south of Great Bear River they are from 10 to 16 miles east of Mackenzie River.

Mackenzie Mountains, extending from Liard River, in latitude 60°, to latitude 66°, form the main northeastern division of the Rocky Mountain system and are offset about 150 miles to the east of the main trend of its axis. The Franklins form a subsidiary and extreme northeastern division of the system, their axis lying from 20 to 50 miles east of the front of Mackenzie Mountains. At Willow Lake River, Franklin and Mackenzie Mountains are only a score of miles apart, and in the vicinity of Wrigley small mountains on both sides of Mackenzie River form connecting links between the two chains.

[1] Manuscript received by the Secretary of the Society March 17, 1924.

[2] This paper is based upon two years' field-work done for the Geological Survey of Canada and is given by permission of the Director. A more detailed description of the geology will be found in the Summary Reports of the Geological Survey of Canada, 1921, Part B, and 1922, Part B.

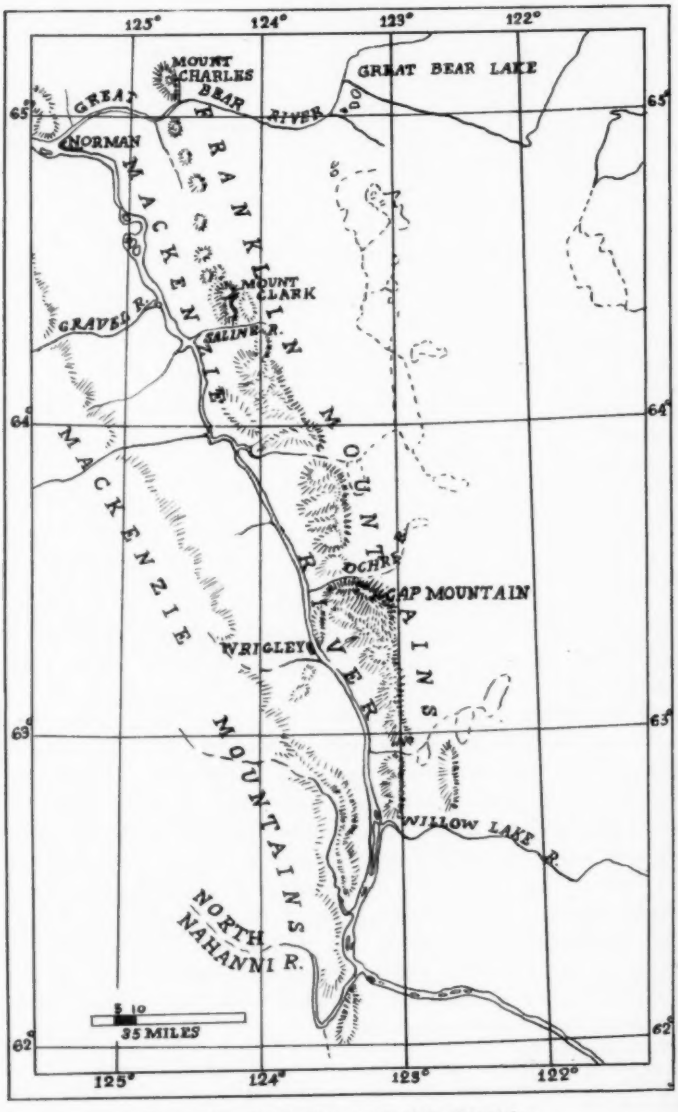

FIGURE 1.—*Sketch Map of Franklin Mountains*

In the vicinity of Norman, a gap of from 50 to 60 miles intervenes between the ranges, but here Bear Rock and Discovery Range form an intermediate range and indicate that the mountain structure is continuous, although not everywhere exposed. It will be shown below that Franklin Mountains possess typical Rocky Mountain structure, and they are interesting, not only because they have been but recently explored, but also because they rise from a lowland plain, as an extreme northeast offset range of the mighty Rockies.

Discovery and Exploration [2]

Franklin Mountains were discovered by Alexander Mackenzie on his memorable trip down Mackenzie River in 1789. A great river and an extensive mountain range commemorate his achievement, but the mountains to the east of the river have been named after Sir John Franklin, who crossed through them on his trip down Great Bear River in 1826. The first geological report on these mountains is that by McConnell, who descended the Mackenzie River in 1888. He recognized in the Franklins "the echelon arrangement so frequently affected by the Rockies," and found Devonian limestone and shale at various places in the mountains and hills near the river. At no place, however, did he penetrate to the heart of the range. He mentions Mount Clark and places Mount Bompas on his map just north of Blackwater River. There is considerable uncertainty as to the identity of the latter mountain. J. Macintosh Bell[3] climbed Mount Charles on his way up Great Bear River in 1900 and gives a brief description of the rocks, suggesting that their age is "Ordovician or possibly Silurian."

The first geologist to penetrate the southern Franklins was E. M. Kindle,[4] who in a brief account of the section of shales, quartzites, iron ore, etcetera, outcropping in the eastern face of Cap Mountain, concludes that "the geological horizon of the Mount Cap ore bed can be stated only approximately, since fossils have not been found in immediate association with the bed. It appears to be within the limits of the Upper Silurian and occurs above beds with Middle Silurian fossils. . . ." As already shown by the writer,[5] the "iron ore" bed and accompanying

[2] For previous geological descriptions of Franklin Mountains, refer to the following reports: R. G. McConnell, Geol. Survey Canada, Ann. Rept., vol. iv, 1891, Part D; Charles Camsell, Science Conspectus, Boston, vol. v, no. 1, 1915; Charles Camsell and Wyatt Malcolm, Mem. 108, Geol. Survey Canada, 1921; E. M. Kindle, Geol. Survey Canada, Summ. Rept., 1919, Part C, and E. M. Kindle and T. O. Bosworth, Geol. Survey Canada, Summ. Rept., 1920, Part B.

[3] J. Macintosh Bell: Geol. Survey Canada, Ann. Rept., vol. xii, 1899, p. 8c.

[4] E. M. Kindle: Geol. Survey Canada, Summ. Rept., 1919, Part C, p. 2.

[5] Geol. Survey Canada, Summ. Rept., 1921, Part B, p. 59.

formations lie far below the Middle Silurian Halysites beds and are in age Cambrian or older. It will be shown below that pre-Cambrian? and Lower and Middle Cambrian formations are represented in the section given by Kindle.

General Characters

Franklin Mountains fall into four main subdivisions, as follows: (*a*) from Willow Lake River to (and including) Cap Mountain; (*b*) from Cap Mountain to the southern rim of Saline River valley; (*c*) the valley of Saline River and Mount Clark; (*d*) the isolated mountains and hills extending from Mount Clark north of Great Bear River.

Subdivision (*a*) includes the southern 50 miles of the Franklins and consists in a broad way of a southerly plunging ridge with a gentle slope to the west and a steep slope to the east. In the south another ridge of similar character and about 15 to 20 miles long parallels the main ridge about 10 miles to the eastward. This ridge has not been visited. Northward the elevation increases, the maximum for the Franklins being reached by Cap Mountain, which rises about 4,700 feet above Mackenzie River, or probably 5,000 feet above the sea. This mountain is bounded on the east and northeast by a curved fault-scarp, with downthrow to the east and northeast estimated at 2,000 feet. Southward this fault passes into an anticline.

The general features of the southern mountains suggest, however, that the range is in the main a tilted block, with a series of fault-scarps controlling its eastern face. This structure is well illustrated by the small ridge extending north from "Roche-qui-trempe-a-l'eau" northeast of Wrigley, which consists essentially of a closed anticline whose eastern side has been downfaulted along the strike of the beds.

In the southern part of subdivision (*a*) the formations exposed are Middle Devonian limestones, with Upper Devonian shales flanking the western slope of the range. Toward Cap Mountain, however, successively lower formations are exposed, including those of Upper, Middle, and Lower Silurian, Middle and Lower Cambrian, and pre-Cambrian? ages.

Subdivision (*a*) best exhibits the typically Rocky Mountain characters, such as precipices, terraces, pinnacles, and domes, the Devonian limestone assuming the most picturesque sculpturing.

Subdivision (*b*).—North of Cap Mountain fault-scarp the general elevation falls away so much that mountains 3,000 feet above sealevel are exceptional. From Ochre River, northward beyond Blackwater River, Upper Silurian, brecciated, gypsiferous dolomite is the prevailing formation noted. It lies with gentle dip to the west and weathers into sub-

dued, flat-topped mountains with rounded, well graded slopes. Some prominent peaks near the eastern front of the range suggest to the distant observer fault-blocks with downthrow on their eastern sides. The range here, which is about 10 miles across, is generally flanked on the west by Middle Devonian limestone; exposures of Middle Silurian limestone occur near the center and older rocks are probably exposed farther east. Minor faulting was observed in the west flank of the mountains on Blackwater River; elsewhere no faulting was noticed.

Subdivision (*c*).—Saline River occupies a valley of mature rock topography, now heavily mantled by glacial drift. Shale exposures along the river contain fossils indicating Middle Cambrian age. To the northward Mount Clark rises as a single prominent mountain ridge, attaining

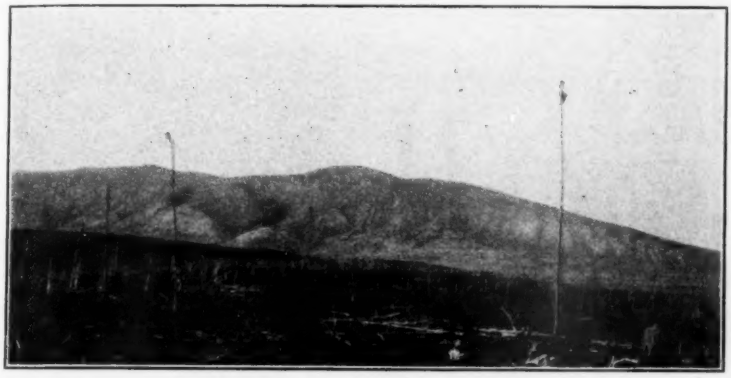

FIGURE 2.—*Mount Clark from Southwest*

an elevation of about 4,700 feet above the sea, and is composed of quartzite of Lower Cambrian age which rests on dark, ferruginous beds thought to be of pre-Cambrian age.

The structure clearly exhibited in Mount Clark consists, in the northern peak, of a closed anticline, which changes to the southeast, along the mountain ridge, into a reversed fault having an upthrow of about 2,000 feet from the eastward. The fault-plane is clearly seen and is accompanied by slickensiding, fault-breccia, etcetera. The strike of the fault-plane is 42 degrees south of east, the dip being to the northeast at an angle of 30 degrees. Another fault on the east side of the mountain appears to parallel the crest of the anticline and separates Mount Clark from a small hill farther to the eastward. This fault is clearly indicated by the attitude of the adjacent strata, and the downthrow to the east is estimated to be at least 1,500 feet.

Thus, due to the mountain-building movements and the adjustments which followed, Mount Clark now appears as upthrust from beneath the formations to the east, which consequently seem downthrown. The eastern limb of the anticline is pivoted in the closed fold of the northern peak, but is overthrust on the western limb in the southern extension of the mountain.

Subdivision (*d*).—Northward from Mount Clark, some five small mountains occur at intervals to the vicinity of Great Bear River. None of these was visited, but the one nearest Mount Clark appeared to be a westerly tilted fault-block exposing Middle Cambrian red shales in its eastern side.

FIGURE 3.—*Northern Peak, Mount Clark*

Author's party and cairn commemorating first recorded ascent.

As seen from Mount Charles, the mountain about three miles south of Great Bear River appears to consist of a westerly dipping fault-block including three formations of Silurian rocks.

Mount Charles, on Great Bear River, is easily accessible and consists of a northwesterly extending ridge, with gentle dip to the west and a precipitous scarp on the east, along the base of which a large stream flows to join Great Bear River. The eastern face suggests a fault-scarp, with down throw equal to or greater than the mountain's height above the plain, which is about 1,500 feet. Mount Charles, with minor ridges to the west, is about three miles wide, and its length, with extensions, is about 10 miles. Northward, low hills could be seen for about 20 miles farther.

Physiography

The Franklin Mountains rise from the Mackenzie Valley lowlands east of the river and interrupt their normal westerly slope. Between the mountains and the river, the muskeg areas are interspersed in many places with morainal ridges and deposits of outwash sand and gravel. Eastward of the mountains, the "great lone land" stretches far beyond the range of vision, an almost featureless plain except for innumerable shallow lakes and gentle swells in the topography characterized by stands of balm of Gilead and white birch. A number of large lakes lie close to the eastern side of the mountain chain and drain into Mackenzie River by such streams as River-between-two-Mountains, Ochre, and Blackwater rivers. All of these rivers cross the mountains through channels that are clearly of preglacial origin. They have been modified by ice-action into the typical U-shape of glacial valleys and their lower courses have been filled with till, gravel, and sand, through which the rivers are now cutting their way. The main divide of the mountains is situated near the eastern border, where the uplift was greatest. Only small streams, however, originate in the mountains themselves.

The general characters of the mountains have been already described. Mature erosion had dissected and modified the uplifted mountain area before the Ice Age. The ice-sheet overrode all the peaks, unless it be the upper 400 feet of Mount Clark, rounding and subduing eminences and planing the valleys into the typical glaciated shape. The direction of ice-movement on Cap Mountain, as shown by striæ, was 12 degrees to 17 degrees north of west and it was 20 degrees north of west on Mount Clark. In both cases local topography had doubtless a directing influence. Morainic ridges west of the southern Franklins extend north 10 degrees west, suggesting the movement of the ice here as being from east 10 degrees north. That the movement was from the eastward is conclusively proven by the presence of boulders of pre-Cambrian granite, gneiss, diabase, etcetera, in the till and as scattered erratics on the flanks and tops of the mountains.

Most of the mountain tops are free of all large rock fragments, either local or traveled. This does not apply, however, to Cap Mountain and Mount Clark. These quartzite ridges show, even at a distance, rounded, subdued topography, which is due essentially to structure. Cap Mountain ridge, with its upturned beds facing the glacier, suffered severe plucking, and many huge blocks of quartzite still rest at spots not far removed from their sources. Among these are worn erratics of small size. The peak of Cap Mountain is covered with immense tumbled,

angular blocks of local quartzite which evidently predate the Ice Age, as erratics of small size are scattered among them. They were evidently too large for the ice-sheet to move at this altitude (about 5,000 feet above sealevel).

In the case of Mount Clark no erratics were observed by the writer over the upper 400 feet of the main peak. The highest part of the mountain consists of a flat area about 100 yards in diameter, which descends 30 feet by a steep talus slope to a terrace about 250 yards wide and extending about 600 yards to the eastward. The direction of the slope between the terraces is nearly parallel to the direction not only of faulting, but of the strike of the strata at this point, and the abrupt declivity may be due to slight postglacial adjustments.[6] The level areas bevel across the structure of the mountain, the upper area covering the crest of the compressed anticline. The surface of these little plateaus is deeply covered with angular quartzite blocks of local origin varying in diameter from 2 inches to 2 or 3 feet. The peak and adjoining terrace of Mount Clark are distinct in character from glaciated areas and suggest the leveling of upland surfaces seen in unglaciated areas of Alaska-Yukon and described under the name of "equiplanation" by Cairnes.[7] The top of Mount Clark appears to be an area which was covered by local snow, but which was not overridden by the continental ice-sheet, since erratics appear to be absent and postglacial time has not been sufficient elsewhere to produce such upland level surfaces, even in the case of much softer rock than the Mount Clark quartzite. Judging by the evidence cited, the upper surface of the ice-sheet was little above the crest of Cap Mountain (5,000 feet elevation) and somewhat below that of Mount Clark (4,700 feet elevation), 75 miles farther north. These mountains were doubtless depressed during Glacial time, and their relative elevation may have been then very different from that of the present.

Postglacial erosion has resulted in the formation of steep slopes (aproned with talus), pinnacles, narrow channels formed by small mountain streams, and minor degrees of "equiplanation" on some of the upland surfaces which are exposed to maximum daily ranges of temperature. On "equiplanation" surfaces parallel horizontal rows of rapidly dissolving limestone pebbles illustrate the manner in which frost, snow, and solution act to reduce upland surfaces. Central pinnacles of deeply weathered limestone usually persist and the surfaces are rarely reduced to a gradient below 15 degrees unless structure has been the controlling

[6] The writer is indebted for this explanation to F. Ebbutt, one of his party.
[7] D. D. Cairnes: Bull. Geol. Soc. America, vol. 23, no. 3, pp. 333-348.

factor. This gradient contrasts strongly with more nearly level surfaces in unglaciated parts of Alaska-Yukon or on Mount Clark.

The frozen condition of the subsoil has prevented the development of effective drainage of the northland in postglacial time, and hence the innumerable lakes and wide muskeg areas. In the mountains, frost action has, however, facilitated the disruption of rock and has consequently been mainly responsible for the more picturesque mountain profiles, which are best developed in the middle Devonian limestone of the comparatively low mountains in the region south of Cap Mountain.

Geology

The geology of the Franklin Mountains may be summarized best in the following table:

Outline of Formations

			Feet
Recent		River silts and soils.	
Pleistocene		Till, outwash sands, and gravels	200±
		Erosion surface.	
Eocene		Silts and semi-consolidated sands and gravels containing lignite beds	200±
		Contact not seen.	
Cretaceous	Upper?	Shales and sandstone containing marine mollusks	100±
		Contact not seen.	
Devonian	Upper—Simpson shale.	Dark gray shale containing thin limestone beds	1,000±
		Conformable contact.	
	Middle	Gray limestones containing fairly rich and varied fauna	2,000±

Disconformity

				Feet
Silurian	Upper	Lone Mountain formation.	Brecciated, massive dolomite containing interbedded gypsum and chert. No fossils	1,600
			Conformable contact.	
	Middle	Mount Kindle formation.	Waterlime and gray magnesian limestone, with Niagara coral fauna	560
			Disconformable contact.	
	Lower	Franklin Mountain formation.	Buff limestone, buff and red shales. *Rhipidomella circulus* and *R. hybrida* near top	500±

Disconformable Contact

				Feet
Cambrian	Middle	Saline River formation.	Buff and green shale, red shale, salt and gypsum. Fossils in shale are *Lingulella* sp., *Micromitra* sp., and *Obolus mcconnelli*	500±
		Covered interval of several hundreds of feet.		
		Mount Cap formation.	Green shales, rusty shales, and sandstones. Fossils include *Lingulella* sp., *Bathyuriscus* 2 sp., and *Ptychoparia* sp.	200±
		Conformable Contact		
	Lower	Mount Clark formation.	Pink quartzite, ferruginous grit and conglomerate. *Saltercella* and *Olenellus canadensis* near top	600+

Disconformity

Pre-Cambrian?	Beltian?	Lone Land formation.	Dark shales, gray and drab shales	375+

Attention is called to the relative completeness of the geological column, which begins in a formation presumably of pre-Cambrian age and ends with Pleistocene and Recent unconsolidated deposits. With the exception of Ordovician and Carboniferous, Paleozoic periods are well represented, and Mesozoic and Tertiary eras are represented by remnants of Cretaceous and Eocene formations. Middle Cambrian[8] formations have been recognized by the occurrence in them of *Micromitra, Obolus mcconnelli, Lingulella, Bathyuriscus, Ptychoparia,* and *Saratogia,* and the Lower Cambrian by *Salterella* and *Olenellus canadensis.* At the base of the Lower Cambrian quartzites and about 600 feet below the horizon of Lower Cambrian fossils are ferruginous beds and conglomerates resting on dark shales. Dr. S. J. Schofield recognizes a close parallel with the conditions at the Beltian-Cambrian contact near Cranbrook, British Columbia, and the shales and lower rusty beds of Cap Mountain and Mount Clark are consequently described provisionally as of pre-Cambrian and possibly of Beltian age. Unless fossils are found below the conglomerates to contradict this conclusion, it will appear to have the same value as pre-Cambrian determinations in southern British Columbia. The exact lithologic similarity of specimens from the two regions suggests correlation with the Belt series. The clastics of the Lone Land formation evidently came from the weathering Archean to the eastward.

The saline, gypsiferous characters of the upper division of the Middle Cambrian are worthy of note, and it is also interesting to compare the gypsum-bearing Upper Silurian formation of the Franklin Mountain region with similar Silurian formations in northern Alberta, Manitoba, the James Bay basin, and with the Salina formation of Ontario and New York.

The Lower Silurian formation is established on the basis of position and the occurrence in it of *Rhipidomella circulus* and *R. hybrida,* which strongly suggest Medina-Cataract time. The Middle Silurian formation contains a rich coral fauna which compares closely with Niagara faunas found elsewhere in America. The Upper Silurian formation is unfossiliferous, but is conformable with the underlying Middle Silurian limestone. At its upper contact it is disconformably overlain by Middle Devonian limestone. From these relationships the age is inferred to be Upper Silurian, and it is confirmatory evidence to find at Mount Charles gypsum beds making up an integral part of the formation, which to the south consists of thick brecciated dolomite weathering into characteristic

[8] All Cambrian fossils have been identified by Dr. C. D. Walcott.

cavernous forms. Even before gypsum beds were seen, the condition of the dolomite led to the inference that gypsum had been dissolved, allowing the formation to collapse. In places, even the lower beds of the Middle Devonian were involved in the brecciating movement. Some gypsum remains in the breccia and it is possible that crushing and brecciation during mountain building mixed the gypsum through the formation, and solution has been mainly confined to the recent period of post-Pleistocene weathering.

The Devonian and higher formations have been well described by previous writers and there is little that need be added here.

Paleogeography

A comparison of the sediments of the Franklin and Mackenzie Mountains shows clearly that the seas were deeper and more continuous to the westward. For example, the Cambrian of the Franklins is composed of clastics entirely, suggesting proximity to the shoreline and source of sediments. In Mackenzie Mountains, on the other hand, Keele[9] ascribes 4,000 feet of argillites, dolomites, calcareous sandstone, and limestone to the Middle or Upper Cambrian. Evidently, moderately deep waters prevailed during a part of the time.

The extent of Upper Cambrian seas is problematical at present, due to the uncertainty of the import of some of the fossils. Hume has reported Middle or Upper Cambrian fossils from Mackenzie Mountains along Carcajou River, and Keele's fossils from Gravel River are referred to either the Middle or Upper Cambrian. Likewise some of the writer's fossils from the Franklin Mountains have Upper Cambrian affinities.

Keele recognized Ordovician formations in Mackenzie Mountains, referring 4,000 feet of alternating argillite, dolomite, and limestone and 1,500 feet of sandstone to this system. Since fossils were found at but one horizon, there seems little proof that this great section is altogether Ordovician, but the former presence of an Ordovician sea in this region is established. There is as yet no evidence of Ordovician sediments to the east of Mackenzie River, and the Ordovician sea may have had its eastern shore in the Mackenzie River valley. In fact, Keele recognizes a thickening of "Ordovician" sandstone toward the river.

The evidence all points to the extension of the Lower and Middle Silurian seas to the eastward of the Franklin range, and the Upper Silurian gypsum deposits bear evidence of the presence of contracted, isolated seas in the same region toward the close of the period.

[9] Joseph Keele: A reconnaissance across Mackenzie Mountains. Geological Survey of Canada, 1910, p. 37.

No Lower Devonian sediments are known in the Mackenzie Valley, nor yet in Manitoba, and it seems unlikely that the unfossiliferous sandstones provisionally assigned by Keele to the Lower Devonian are really of that age. It is probable that northwestern North America, including the region under consideration, was emergent during Lower Devonian time. Rocks of Middle and Upper Devonian age are exposed in the vicinity of Franklin Mountains, and the seas in which they were deposited evidently extended a considerable distance farther to the eastward.

No Carboniferous rocks have been found farther north or east than Hume's locality of the Kinderhook fauna on Liard River, and the extent of the Carboniferous seas is somewhat in doubt.

Keele found Triassic fossils in limestone on the Upper Stewart River, but as no other Triassic occurrences have been reported from the region, the seaways probably did not extend far to the eastward.

Jurassic time appears to have been marked by emergence and possibly by warping, and the seaways of Cretaceous time may have been restricted to valleys controlled by structure and differential erosion.

The Cretaceous sediments along the Mackenzie are clastics, but contain a typical marine fauna. Sediments of this age were involved in the Laramide mountain building, as shown by Hume, in the vicinity of Liard River and, as described above, on Bear River.

The Tertiary deposits are fresh water in origin and represent in large measure the sediments derived from the destruction of the upthrust Cretaceous beds. Evidently a Tertiary river system was ancestral to the present Mackenzie system.

Mountain Building

Franklin Mountains and adjacent portions of Mackenzie and Bear River valleys have not furnished complete evidence of the age of mountain building. The Upper? Cretaceous sandstones and shales of Mackenzie Valley probably rest on Upper Devonian shales, and the Cretaceous of the rapids on Bear River may rest on Upper Silurian beds, but in neither case are the relationships known. Hume[10] has recently found Cretaceous sediments affected by mountain folding in the southern Mackenzie Mountains north of Liard River. He[11] also found a Kinderhook fauna (Lower Carboniferous) in this same region.

Although not yet discovered nearer Franklin Mountains, Carbonif-

[10] Geological Survey of Canada, Summary Rept., 1922, Part B, p. 48.

[11] G. S. Hume: A Kinderhook fauna from the Liard River, N. W. T., Canada. American Journal of Science, vol. vi, July, 1923, pp. 49-52.

erous formations may have existed there formerly. The absence of Triassic and Jurassic sediments suggests very strongly that the region was above sealevel in early and Middle Mesozoic time, and the presence of Cretaceous sediments in valleys underlain by Upper Devonian shales still further suggests pre-Cretaceous erosion valleys filled by Cretaceous seas. The calcite and selenite veins and the crystallization, silicification, and dynamic metamorphism of the Silurian and Devonian sediments indicate disturbances which did not affect the Cretaceous beds. There is to be added the evidence of chert pebbles in the Cretaceous conglomerates. These pebbles evidently came from Paleozoics (possibly Ordovician) exposed by erosion in the Mackenzie-Yukon Mountains. The combined evidence points to uplift and deep erosion before Cretaceous time, at least in the region of the Yukon-Mackenzie watershed, which Keele[12] recognized as of earlier origin than the Mackenzie Mountains.

As limestones containing Triassic fossils occur on the Upper Stewart River, it seems probable that the uplift occurring at the close of the Paleozoic era did not entirely exclude the sea from the region considered, and that the general disturbances accompanying the intrusion of the Coast Range batholith were responsible for the earlier uplift of the Yukon-Mackenzie watershed.

A second uplift and mountain building occurred, however, after the Cretaceous sediments of the Mackenzie basin were deposited, as already stated by Kindle and others. The Cretaceous sediments in the vicinity of Franklin Mountains are somewhat tilted, and the major drainage system was well established before the Eocene deposits were laid down. Not only are these deposits undisturbed, but they contain, in conglomerate beds, large quantities of chert pebbles which were probably derived from destruction of the Cretaceous conglomerates. It may be argued that these pebbles and those of the Cretaceous have come from the same source, but the fine polish, excessive wear, and great quantity of the pebbles strongly support the conclusion that they have been derived from the erosion of the near-by exposures of Cretaceous formations.

The present mountains are doubtless a product of the Laramide revolution, during which the Rocky Mountains were built. There is good evidence, however, for believing that the Paleozoics had been at least uplifted and differentially eroded in post-Devonian and pre-Upper Cretaceous time. The Jurassic period during which the Coast Ranges were built was probably the time of this uplift.

[12] J. A. Keele: Reconnaissance across the Mackenzie Mountains. Geological Survey of Canada, 1910.

Origin of Franklin Mountains

A map of the northwest mountains of America illustrates clearly the echelon arrangement of the Mackenzie and Franklin ranges and demonstrates the essential parallelism of their axes with those of the ranges to the west, in the heart of the Cordillera.

The cause of the echelon arrangement may be considered best in the light of the relationships of the fronts of the Rocky Mountain ranges and the flanking sediments to the east. From Liard River south 2,000 feet or more of interbedded sandstones and shales of Mesozoic age occupy the foothills and adjoining plains region. These incompetent sediments have not transmitted mountain-building thrusts to any great distance to the east, but have absorbed the strain within themselves by intricate folding and faulting in the disturbed belt, which includes the foothills. In the southern Rockies of Canada, as long ago pointed out by Dawson, foothills are lacking, and older rocks from the west have been overthrust onto the disturbed belt, forming, for example, the Clarke range, which lies east of the main front of the Rockies.

From Liard River north, the Mackenzie and Franklin Mountains front for the most part on the same Paleozoic formations that make up the mountains themselves. South of the Franklins the Mackenzie Mountains are flanked by thick deposits of Upper Devonian shales, which also underlie the trough occupied by Mackenzie River between Mackenzie and Franklin Mountains, except where overlain by limited areas of Cretaceous and Tertiary sediments.

Franklin Mountains overlook a flat swampy country probably underlain by pre-Cambrian and Paleozoic sediments, the latter being of no great thickness. In the vicinity of Great Bear River, Cretaceous sediments front the Franklins, and from here northward the range appears to die out, its course probably being overlain by soft Cretaceous sediments.

At their northern end the Mackenzie Mountains terminate at the Cretaceous area extending southward from Mackenzie Delta and ending in the form of a plateau.

The facts set forth above may be summarized for northern Canada as follows:

Ranges possessing typical Rocky Mountain structure occur east of the main front of the Rockies only in areas free from great thicknesses of bordering Mesozoic and Tertiary strata. Elsewhere, as, for example, in the case of the Clarke Range, extension is due to overthrusting.

It is clear that the extent of mountain building is affected by the

amount of incompetent strata which absorb the thrust. Thus, in general, the Rocky Mountains of British Columbia and Alberta are flanked on the east by thick deposits of Mesozoic sandstones and shales which have acted as a buffer. In the case of the overthrust area, as, for example, in the Clarke Range, the resistance of the flanking strata has been rendered ineffective in controlling the eastward extension of the mountains, in that the Mesozoics themselves have been overridden by older strata coming from the west. Mackenzie and Franklin Mountains have no such confining overburden along their eastern slopes and the thrust from the west has resulted in a greater eastward extension of the folds.

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NEW TYPE OF STRUCTURE IN THE APPALACHIANS[1]

BY GEORGE W. STOSE

(Presented in abstract before the Society December 29, 1923)

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PREVIOUSLY RECOGNIZED STRUCTURES

The prevailing structure of the Appalachians consists of elongate longitudinal folds that trend northeastward, most of which are overturned toward the northwest and many of which are broken and overthrust in that direction. These folds were produced by the yielding of the rocks to earth forces that compressed them at right angles to the axes of folding during Paleozoic time, largely at or near its close. In the Piedmont portion of the Appalachians another form of structure occurs, block-faulting, which was produced by the settling and adjusting of great earth blocks in Triassic time, after the compressive forces subsided or were relieved. Triassic sediments, which had been deposited in basins produced by the sinking of great longitudinal areas, were further depressed at or near the close of the Triassic period by normal drop-faulting on one side of the basin and the tilting of the depressed block. Although block-faulting and tilting were probably not restricted to the areas of Triassic sediments, such normal drop-faults have been recognized at but few places in pre-Triassic rocks because most of these rocks in the Piedmont are crystalline rocks which are so greatly metamorphosed that their geologic structure is difficult to decipher.

[1] Manuscript received by the Secretary of the Society March 24, 1924.
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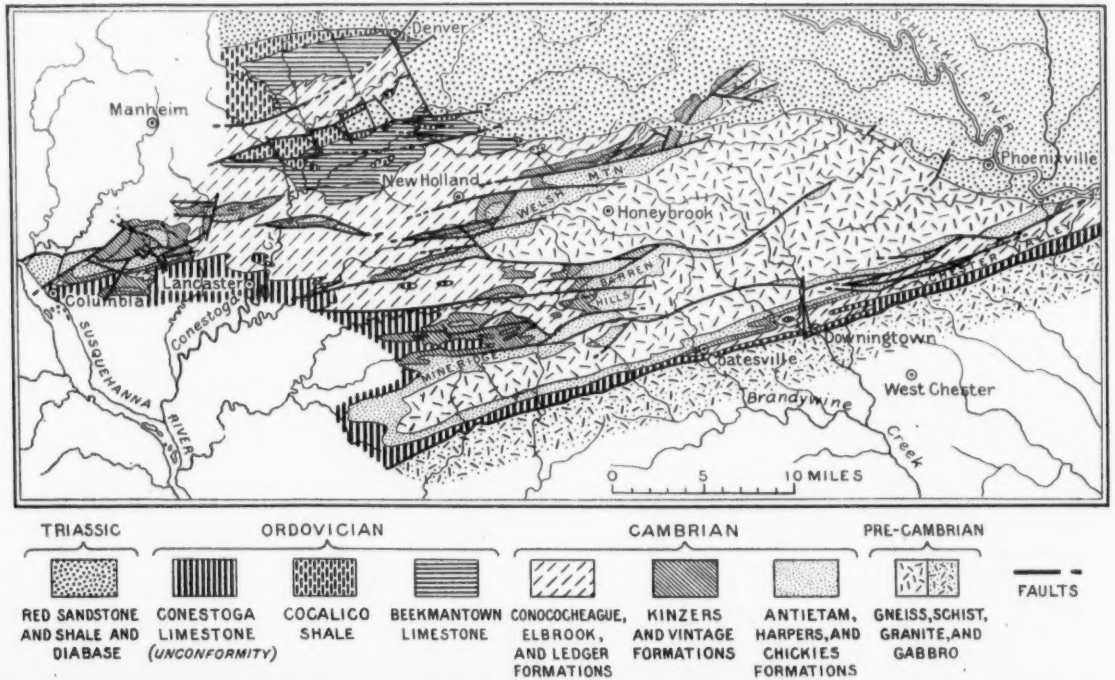

FIGURE 1.—*General geologic Map of the Lancaster Valley and surrounding Area in southeastern Pennsylvania*

New Type of Structure

In the Piedmont of southeastern Pennsylvania the rocks are poorly exposed and fault-planes are almost never seen, so that most faults are inferred solely from the observed areal relations of the formations. These faults have generally been considered to be thrust-faults of the Appalachian type, but in the Paleozoic rocks of the Piedmont of Pennsylvania, recently mapped and studied by the writer and Anna I. Jonas, representing the Pennsylvania Geological Survey, certain fault structures do not seem to be of this type.

In Chester Valley, east of Downingtown, in the area previously mapped for folio publication by Miss F. Bascom, a long, narrow lens of Cambrian quartzite, schist, and limestone occurs in the midst of younger Cambrian limestone. This linear belt of older rocks, which lies north of Planebrook, is aligned and evidently genetically connected with a wedge-shaped area of the same rocks north of Whitford, which is apparently a faulted anticlinal finger of the eastward-plunging Mine Ridge anticline north of Downingtown. Similar long, narrow, faulted anticlinal ridges of Cambrian quartz-

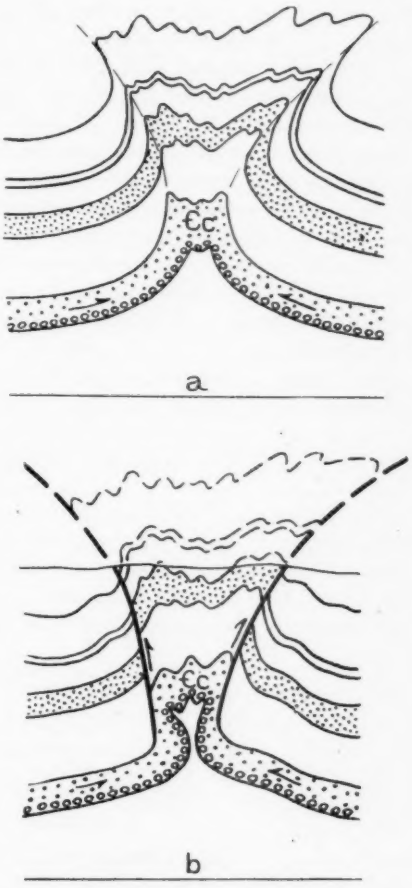

FIGURE 2.—*Theoretical Section along the Line L-L', in Figure 6*

Drawn on the assumption that the structure is a faulted fan fold in which the Chickies quartzite (*Cc*) forms the core and is the thrust-bearer.

***a*. Before faulting.**

***b*. After Chickies quartzite broke and transmitted the upthrust along steep fault-planes.**

FIGURE 1.—*General geologic Map of the Lancaster*

ite and schist extend westward into the limestone lowland from the westward-plunging end of the Welsh Mountain anticline. Elongated lenticular areas of Cambrian quartzite and overlying limestones, similarly surrounded by younger limestones, occur in the valley north of Lancaster. The general areal relations at these places are shown on the general map (figure 1). Attempts to draw structure sections across these areas on the assumption that they are anticlines overturned and overthrust toward the northwest in typical Appalachian fashion were not successful, for they are apparently faulted on both sides. Neither do they appear to be closely compressed fan folds overthrust outward on both sides, for the dips of the beds at the surface indicate normal anticlines and not fan structure. Furthermore, in drawing theoretical sections on the assumption that the structure is a faulted fan fold (see figure 2), the massive Chickies quartzite that forms the core of the fold would be the bed to break and transmit the upward and outward thrusts, but in the narrow parts of the faulted belts there is not room for such a core of Chickies quartzite and therefore there would be no competent bed to transmit the thrust. They are therefore regarded by the writer as a new type of structure, which is made the subject of this paper.

The Rock Formations

The rock formations that are involved in the problem are a basal Cambrian arenaceous series that rests on pre-Cambrian gneiss, schist, and granite; overlying Cambrian and Ordovician limestones, dolomites, and shales; and Triassic red arkosic sediments. Their sequence, thickness, and relations are given in the following table:

Generalized columnar Table

		Feet
Triassic	Soft red sandstone	1,000+
	Hard conglomerate and red and gray sandstone	1,000±
	Soft yellow and red arkosic sandstone	500– 800±
	Unconformity	
Ordovician	Conestoga limestone	500±
	Unconformity	
	Cocalico shale	1,000±
	Beekmantown limestone	2,000±
Cambrian limestones	Conococheague limestone	900±
	Elbrook limestone	500±
	Ledger dolomite	1,000±
	Kinzers formation	150– 0
	Vintage dolomite	100– 650±

		Feet
Cambrian arenaceous rocks.	Antietam quartzite	0– 200
	Harpers schist	1,000–1,500±
	Chickies quartzite	500–1,000±
	Hellam conglomerate member	150– 600
	UNCONFORMITY	
Pre-Cambrian	Gneiss, schist, granite, gabbro.	

TRIASSIC GRABEN

Near Ephrata, northeast of Lancaster, a narrow belt of Triassic sandstone and Ordovician shale furnishes a possible solution of the problem. The Triassic sandstone, which here lies on the Ordovician Cocalico shale and Beekmantown limestone, the youngest Paleozoic rocks in the area, has been preserved in a down-dropped fault-block. (See map, figure 3.) Not only has the block been faulted down on the west side and tilted westward, as is common with most areas of Triassic rocks in this region, but it has also been faulted down to some extent on the east side, so that a narrow mass of Triassic rocks occupies a graben. (See sections, figure 4.) The dropped block is broken into many smaller angular blocks by cross-fractures, which offset the beds and also the bounding faults in most places. As the downthrow of these cross-faults is mostly on the east side, the amount of down-faulting of the Triassic basin diminishes westward, and Triassic sandstone is not now present beyond the cross-fault at Akron. Southwest of this point the Ordovician Cocalico shale in a faulted syncline composes the fault-block. That the Paleozoic rocks beneath the Triassic sediments in the eastern part of the block are also synclinal in structure is shown by the fact that Cocalico shale and underlying Beekmantown limestone outcrop with northwest dips along most of the southeastern margin of the block and patches of the shale are caught in fault-blocks along the northwestern margin. It appears, therefore, that the Triassic down-dropped block or graben coincides in position with the deeper part of a syncline formed during post-Carboniferous folding. (See figure 4.) In other words, the syncline, formed by compressive forces, seems to have persisted as a sinking element into post-Triassic time, when, in the readjustment by normal drop-faulting, it became a dropped block or graben. In the main Triassic area to the northwest, the southeastern edge of which is shown on the map in figure 1, the Triassic sediments also overlie Cocalico shale, and it is probable that the basin in which that part of the Triassic was deposited was synclinal during the post-Carboniferous folding and persisted as a sinking element during most of Triassic time.

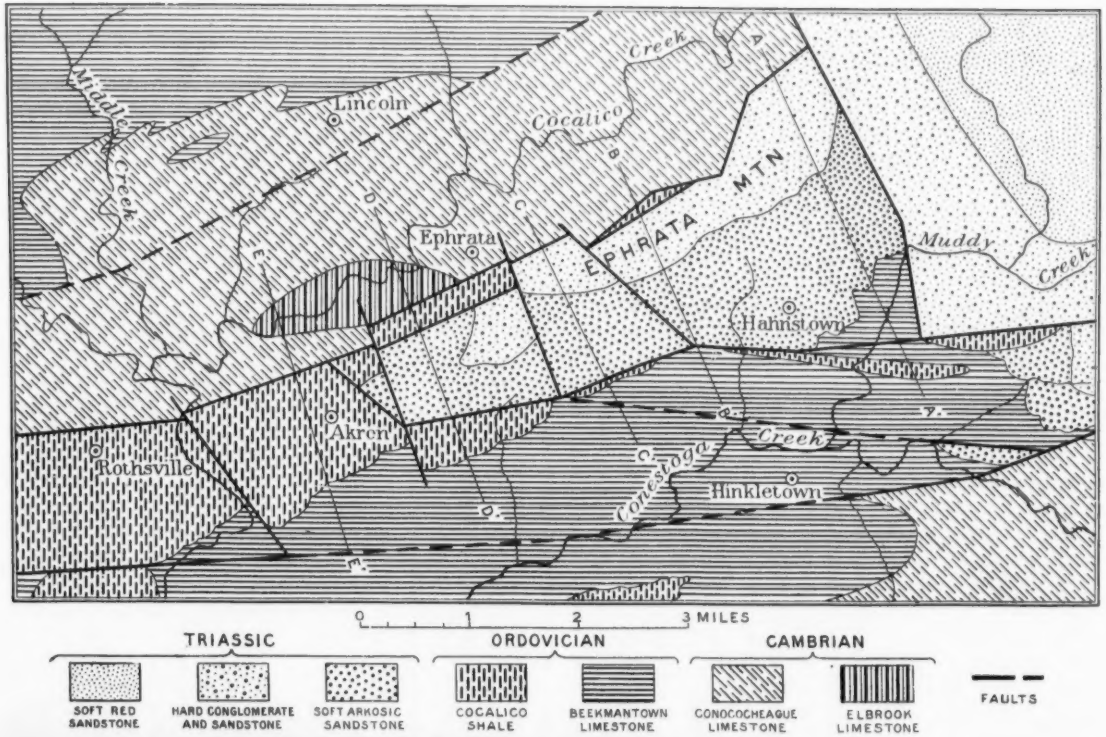

FIGURE 3.—*Detailed geologic Map of Area in Vicinity of Ephrata*
Illustrating Triassic graben.

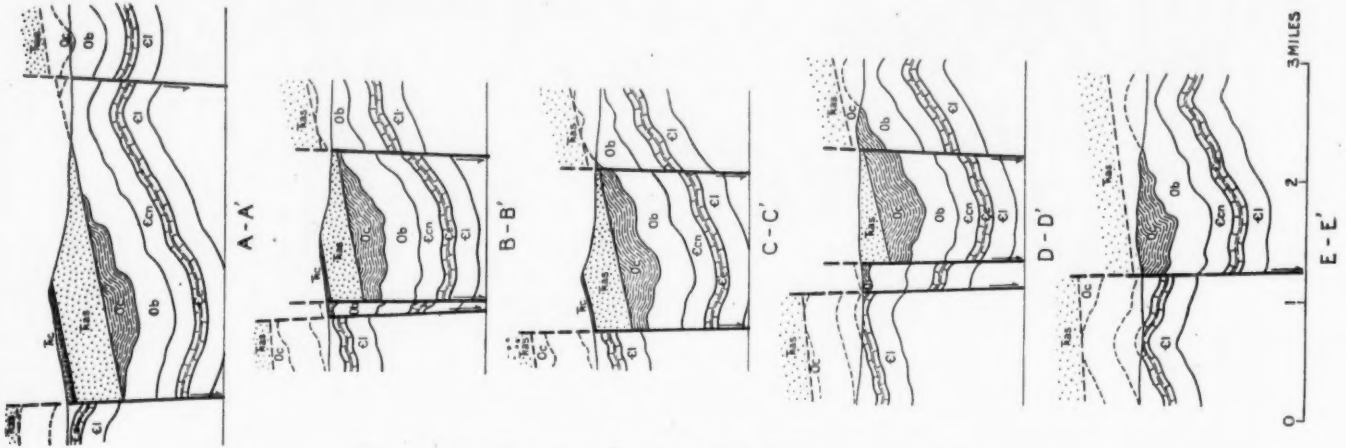

FIGURE 4.—*Structure Sections across the Triassic Graben mapped in Figure 3*

Showing nature of the block-faulting and synclines of Palæozoic rocks beneath Triassic dropped blocks. *Cl*, Ledger dolomite; *Ce*, Elbrook limestone; *Ccn*, Conococheague limestone; *Ob*, Beekmantown limestone; *Oc*, Cocalico shale; *Tras*, Triassic arkosic sandstone; *Trc*, Triassic conglomerate.

FIGURE 3.—*Detailed geologic Map of Area in Vicinity of Kipharta*

Illustrating Triassic graben.

Anticlinal Horsts

An opposite movement seems to have taken place along the flanks of attenuated faulted anticlinal branches of the Welsh Mountain anticline at its plunging west end, and of similar narrow faulted anticlines in the limestone valley to the west. These folds were formed by compressive forces in late Paleozoic time, probably at the close of the Carboniferous. They may have been broken and thrust-faulted to some extent in the process of folding, but the marginal faults seem to be explainable only on the assumption that they are of the normal drop-block type. During the Triassic period these anticlines apparently persisted as stable elements, and adjacent synclines were sinking elements; so that, in the readjustment by block-faulting and tilting at the close of the Triassic, great blocks on the flanks of the anticlines were faulted down along steeply inclined, nearly parallel breaks. Thus long, narrow, lenticular masses of older rocks were left as anticlinal horsts in the limestone and are now being bared by erosion. (See figure 1.)

Details of Structure

The Welsh Mountain anticline is a broad anticlinorium which exposes a wide area of pre-Cambrian rocks in the vicinity of Honeybrook. The Cambrian quartzites which form Welsh Mountain on the northwest flank of the anticline are faulted out along the south side. (See figure 1.) On the theory that the displacement is a thrust-fault, the pre-Cambrian rocks north of the fault must have been thrust southward against the limestones in a direction opposite to that of most Appalachian faults. The evidence, however, is strongly in favor of the break being a normal drop-fault, the block to the south having dropped about 4,000 feet. (See section F, figure 7.) There is some faulting on the north side also, but the throw is not so great. The main anticline is terminated abruptly at the west end of Welsh Mountain by a diagonal cross-fault, whereby the Ledger dolomite on the west is dropped to the level of the base of the Cambrian in the anticline. The compound character of the anticlinorium is best shown in the plunging end of the fold, especially west of the diagonal fault, where it passes into two low but pronounced anticlines. (See figure 5.)

The Antietam quartzite in the northern anticline makes a low ridge, called Laurel Hill, about three miles long. The Ledger dolomite is faulted down by a normal drop-fault against the south side of the Antietam quartzite, and to the west the Ledger cuts diagonally across the Antietam and Vintage formations. A minor drop-fault is probably present on the

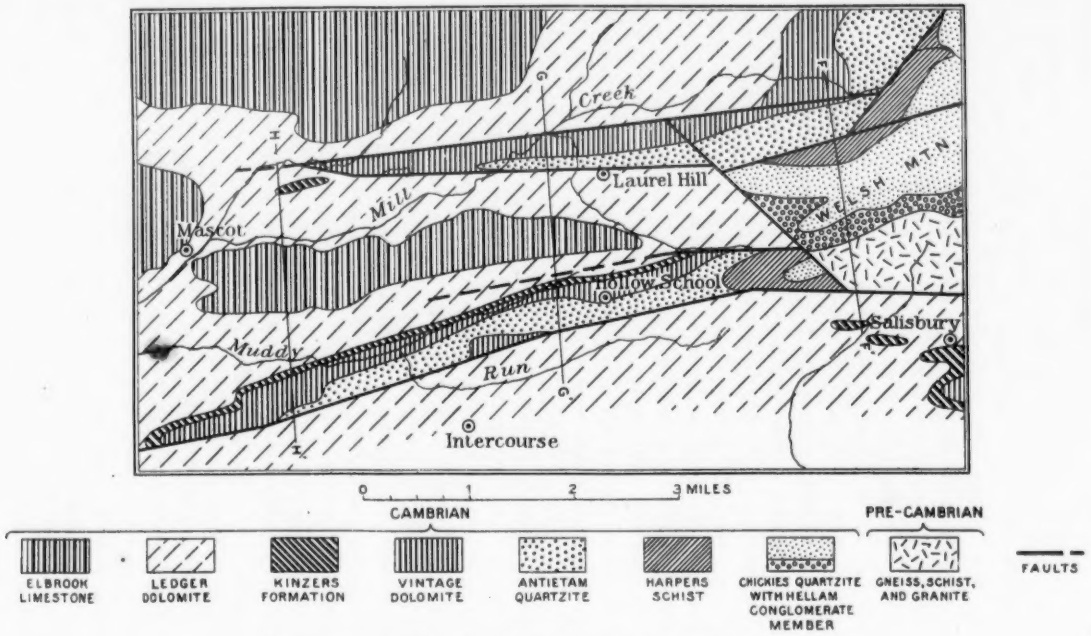

FIGURE 5.—*Detailed geologic Map of Area West of Welsh Mountain*

Illustrating anticlinal horsts and showing their relation to Welsh Mountain anticline.

north side of the anticline, but is not so evident, because it lies within the limestone. The Kinzers formation is apparently absent here. (See map, figure 5.) The Antietam quartzite in the southern anticlinal finger makes the Hollow School ridge, which is about five miles long. The Ledger dolomite is here also faulted down against the Antietam quartzite on the south side, being a small area of Vintage dolomite infolded north of the fault at one place. Southwestward, where the fold plunges, the Antietam, Vintage, and Kinzers formations are in turn cut off by the fault and brought against the Ledger dolomite. At the eastern end of the fault-block Chickies quartzite and Harpers schist, brought up in the anticline, are faulted against Ledger dolomite not only on the south side, but also on the north side where a drop-fault cuts sharply across the Harpers, Antietam, Vintage, and Kinzers formations and is lost beyond in the limestone valley. It is to be noted that the main fault movement in the Welsh Mountain anticline and in each of its branch anticlines is essentially the same as that in the faulted blocks of Triassic rocks near Ephrata—that is, the blocks are faulted down on the north side, tilting them northward. There are, however, no flat-lying Triassic beds present to show this tilting. The minor faulting on the north side of the uplifted anticlinal blocks makes them anticlinal horsts. (See sections F and G, figure 7.)

The lenticular faulted areas north and northeast of Lancaster are not in strike with the Welsh Mountain uplift, but are offset to the north, en echelon. They also pass north of the anticlinal hills of Cambrian quartzite northwest of Lancaster. (See figure 1.) The Fruitville faulted belt consists of a main anticline, in which the Antietam quartzite makes the Fruitville hill, and several minor anticlines which bring up small areas of Antietam in the Vintage dolomite. (See figure 6.) Along the south side of the uplifted block Ledger dolomite and Elbrook limestone are faulted down in contact with the Antietam quartzite and Vintage dolomite. On the north side the fault is not so great, as the north dips of the anticline carry the Antietam quartzite below the surface, so that the Vintage dolomite and Kinzers formation are in fault contact with the Elbrook limestone. (See sections K, L, M, figure 7.) The whole fault-block is broken by a normal cross-fault at Fruitville, which offsets the Antietam quartzite hill one-fourth mile.

The faulted block south and west of Mechanicsburg consists of two main anticlines, each of which brings up Antietam quartzite and older rocks, and Vintage dolomite is inclosed between. (See figure 6.) The quartzite in the southern anticline makes a low ridge south of Mechanicsburg. The northern anticline is the main upfold and brings to the

surface not only Antietam quartzite but also Harpers schist, which make the more prominent ridge west of Mechanicsburg. A narrow anticlinal tongue of the fold extends westward toward a small anticlinal hump that makes a detached hill in the loop of Conestoga Creek north of Binkley. At the creek a small mass of Chickies quartzite and Harpers schist, which is entirely surrounded by Vintage dolomite, is apparently a minor block caught between branch faults. The whole fault-block is bounded by two main drop-faults. (See sections I and J, figure 7.) The one on the south side brings the Elbrook and Ledger limestones down against the Antietam quartzite and Vintage dolomite. A somewhat parallel fault on the north side drops the Conococheague limestone against the Vintage dolomite at the west and against the Antietam and Harpers formations to the eastward, and then apparently cuts diagonally across the syncline of Vintage dolomite south of Mechanicsburg. (See figure 6.)

The structure of the faulted block north of Planebrook, in Chester Valley, would be very obscure if it were not for the schist hill two miles to the northeast. Most of the area here mapped as Chickies quartzite (see figure 8) consist of low hills covered with deep sand containing thin fragments of laminated white quartzite and quartz plates, which were apparently derived from the disintegration of crumbly Chickies quartzite. At the east end of the fault-block a prominent hill composed of hard quartzose schist with thin beds of quartzite is apparently Harpers formation. It passes eastward across the strike into beds of fossiliferous, calcareous, ferruginous quartzite, which is typical of the upper part of the Antietam, and this is succeeded by Vintage dolomite. The beds are vertical and strike diagonally across the fault-block, and apparently represent part of the southeast limb of an anticline which is bevelled off on both sides by drop-faults. (See section N, figure 7.) One mile west of Planebrook the faulted wedge of quartzite does not reach the surface, the inclosing Ledger dolomite apparently here concealing the fault (see section O), but northeast of Exton the disintegrated quartzite again makes low sandy hills, and northwest of Exton hard well-bedded Chickies quartzite is exposed in a large quarry. The structure of this part of the faulted belt is fairly clear and is undoubtedly similar to that of the plunging folds at the west end of Welsh Mountain—that is, it is a faulted anticlinal branch of the eastward-plunging Mine Ridge anticline. (See figure 8.) North of Downingtown the Mine Ridge anticline exposes a belt of pre-Cambrian rocks one mile wide, but about two miles to the east the fold abruptly plunges, so that the pre-Cambrian rocks dip beneath the surface. The Cambrian conglomerate, quartzite, and schist project eastward into the valley in two anticlinal prongs of the plunging

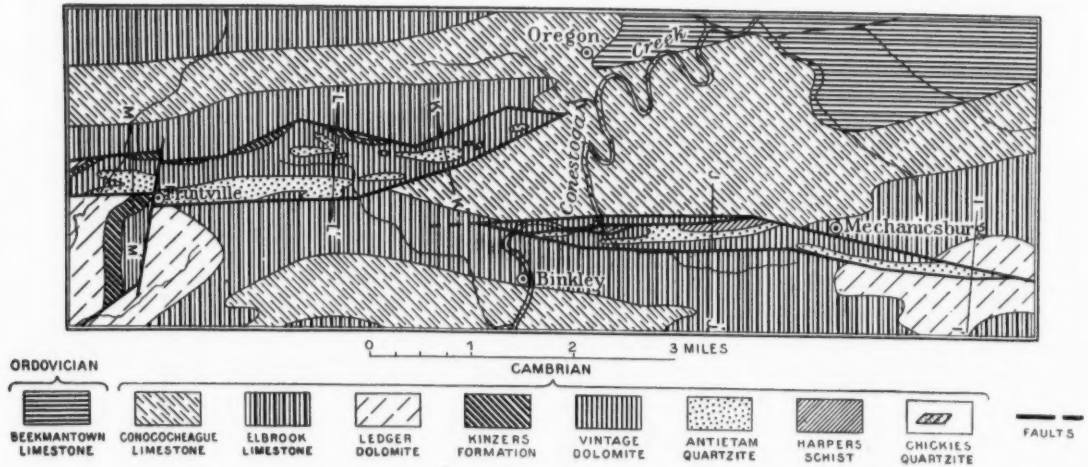

FIGURE 6.—*Detailed geologic Map of Area between Fruitville and Mechanicsburg*
Illustrating faulted anticlinal blocks.

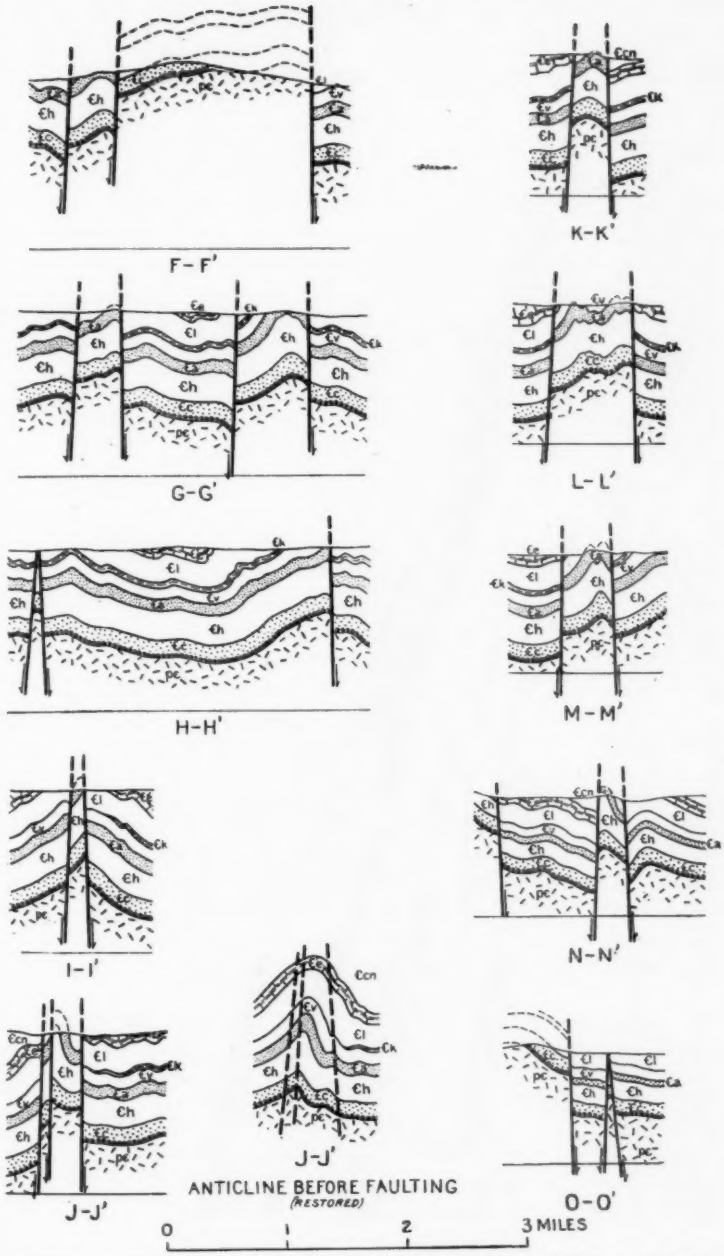

FIGURE 7.—*Structure Sections across Fault-blocks mapped in Figures 5, 6, and 8*

Showing nature of the block-faulting. *pc*, pre-Cambrian; *Cc*, Chickies quartzite with basal Hellam conglomerate member; *Ch*, Harpers schist; *Ca*, Antietam quartzite; *Cv*, Vintage dolomite; *Ck*, Kinzers formation; *Cl*, Ledger dolomite; *Ce*, Elbrook limestone; *Ccn*, Conococheague limestone.

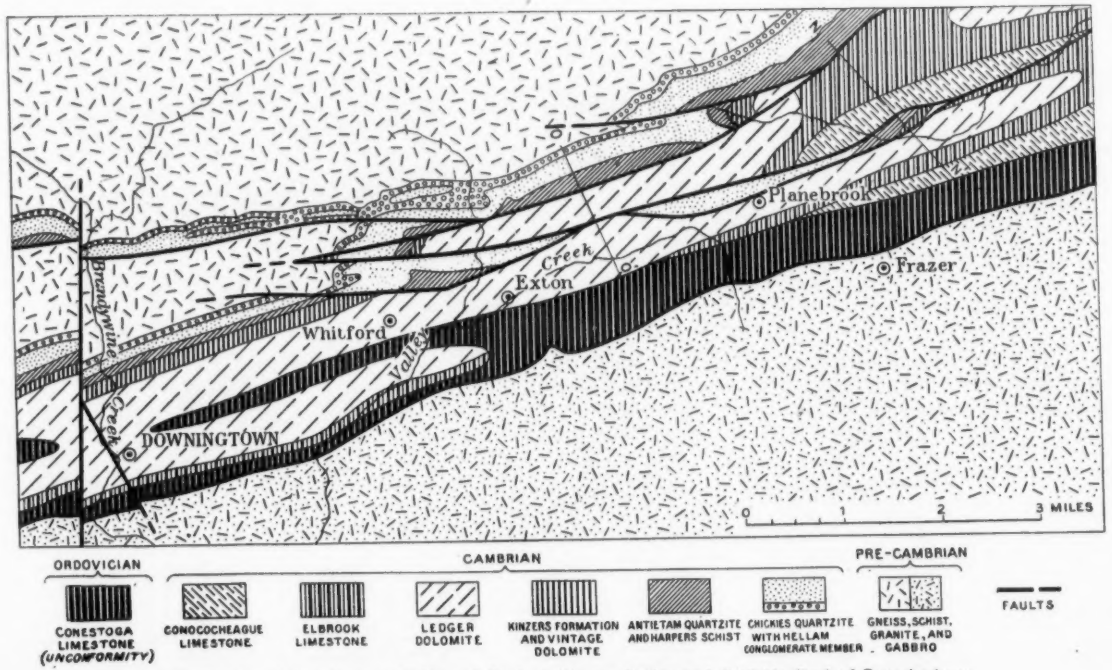

FIGURE 8.—*Detailed geologic Map of Part of Chester Valley and Vicinity East of Downingtown* Illustrating anticlinal horsts.

anticline. The southern prong is attenuated and faulted on both sides by drop-faults, Ledger dolomite being dropped down on both flanks of an anticline of Chickies quartzite. The structure may be further complicated by cross-faults, similar to the one at Downingtown, which offsets the whole Mine Ridge anticline and the limestone valley to the south more than one-fourth mile. Although the structure of the part of the fault-block north of Planebrook can not be determined because of the general disintegrated character of the Chickies quartzite, it is believed to be the attenuated end of the faulted anticline to the west.

The fault-planes are nowhere exposed because the rock outcrops are so poor, but many of them are marked by vein quartz, residual masses of which are left in the soil. Some of these veins are two or three feet thick and their residual masses are a material aid in locating the faults. The fault on the north side of the Fruitville block is so marked at its east end. A thick quartz vein forms the fault contact of Chickies quartzite and sheared Vintage dolomite at Conestoga Creek west of Mechanicsburg, which is the best exposure of a faulted block in the area, and a steeply south-dipping contact is suggested by the observed relations. Elsewhere large springs aid in the location of fault-planes. South of Landisville, at the western edge of the area mapped in figure 1, a Triassic diabase dike marks a fault-plane by following it for a short distance. This fault, therefore, antedated the dike.

Some geologists recently expressed doubt as to whether certain graben and similarly faulted areas in various parts of the world were formed by dropped-block faulting brought about by the adjustment of earth blocks under conditions of tension, as heretofore believed, and propose instead the theory that the sides of the graben were upthrust along steeply inclined planes under compressive stresses. These geologists would, no doubt, be inclined to favor the theory that the structures here described were likewise upthrusts along steeply inclined planes. There is, to my mind, no shadow of doubt that the blocks inclosing the gently tilted but otherwise undisturbed Triassic rocks in this area were produced by normal drop-faulting and tilting of blocks. The evidence is not so conclusive, however, for the faulted anticlinal horsts, but, as previously shown, dropped-block faulting best accounts for the observed relations.

Summary of Conclusions

The writer has observed in the Paleozoic sedimentary rocks of the Piedmont of southeastern Pennsylvania typical Appalachian folded and overthrust structures and Triassic normal dropped-block faulting in both

Triassic sediments and the underlying Paleozoic rocks, and in addition he has discovered what he considers to be a combination of these structures of a new type. He has concluded that the normal dropped-block faulting of late Triassic age has in places been superposed on folded compressed structures of late Paleozoic age, giving rise to graben with synclinal substructure and to anticlinal horsts of Cambrian quartzite on the flanks of which there are down-dropped blocks of younger limestone.

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STRATIGRAPHY OF CRETACEOUS-EOCENE TRANSITION BEDS IN EASTERN MONTANA AND THE DAKOTAS[1]

BY W. T. THOM, JR., AND C. E. DOBBIN

(*Presented before the Society December 28, 1923*)

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INTRODUCTION

The Cretaceous-Eocene boundary, or Laramie problem, is one of the outstanding questions of North American geology, and one in which the writers have become deeply interested as the result of nine and six field

[1] Manuscript received by the Secretary of the Society May 27, 1924.
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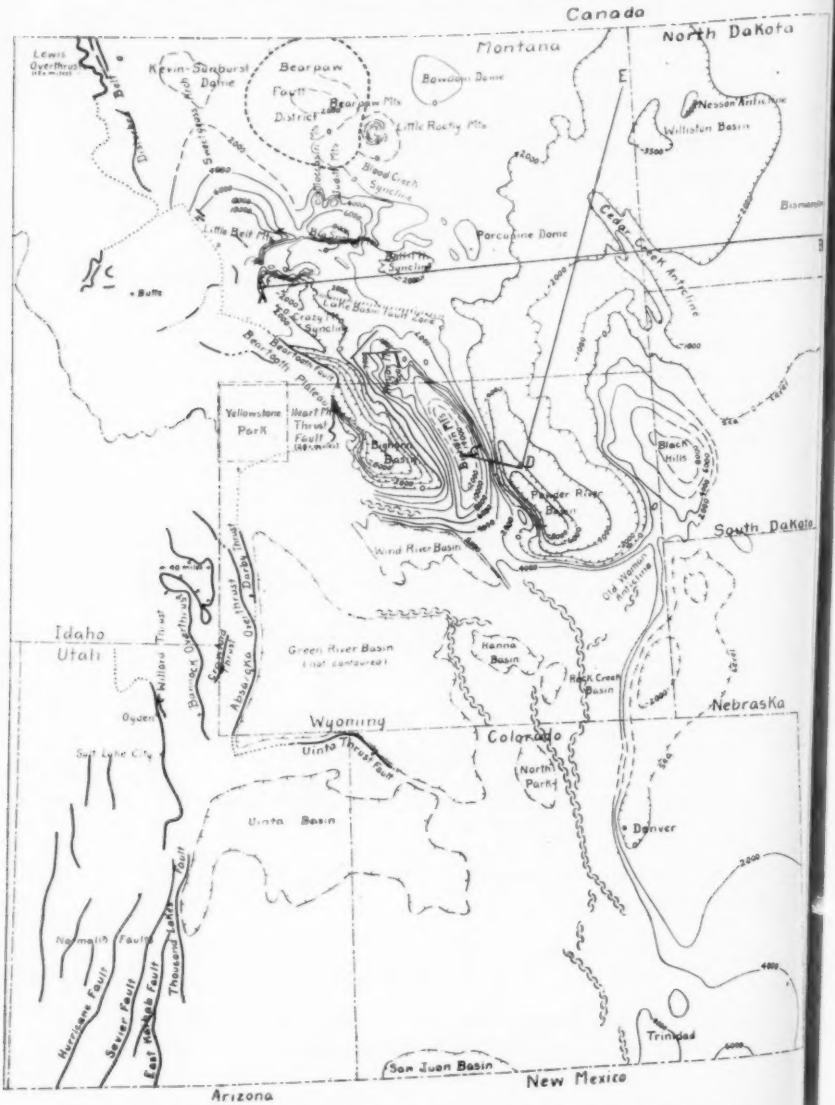


FIGURE 1.—*Structural sketch Map of the northern Great Plains and related Areas*

Structure contours on Dakota sandstone or "First Cat Creek sand."

seasons, respectively, spent as members of the U. S. Geological Survey parties in Montana, Dakota, and Wyoming areas. The intimate knowledge of local stratigraphy thus gained, through coal or oil and gas work in a number of fields, has afforded a background for extensive reconnaissance studies carried out in the spring and autumn of 1923, during which critical sections in Montana and Dakota areas were reexamined, and the results obtained by earlier workers in local and more or less detached fields were interpreted and integrated. In this work an earnest effort has been made to apply all practicable checks, to the end that the conclusions reached may be as free as possible from coloring by personal bias and from errors due to unverified observations.

ACKNOWLEDGMENTS

During May, 1923, the junior author was accompanied by J. B. Reeside, Jr., in a reconnaissance study of the Fox Hills sandstone in Dakota and eastern Montana areas. In 1921 Dr. T. W. Stanton accompanied the senior writer in a reconnaissance examination of Fox Hills areas between Mosby and Wolf Point, Montana, and in the vicinity of Glendive. Microscopic examinations of specimens of the Cretaceous and transition strata of the northern Plains have been made for the writers by C. S. Ross, of the U. S. Geological Survey, and acknowledgments are also due to E. R. Lloyd, A. J. Collier, and E. T. Hancock, with whom the writers have served as field assistants,[2] [3] [4] and to the many other workers in this region, some of whom have contributed the articles listed in the appended bibliography. Thanks are also due to many colleagues of the U. S. Geological Survey for valuable suggestions and constructive criticisms.

PART I. STRATIGRAPHY OF THE NORTHERN PLAINS

GENERAL STATEMENT

The principal uplifts and depressions of the northern Great Plains (see figure 1) were incipient in Upper Cretaceous time,[5] and their development was directly reflected in the character and localization of the Lance, Fort Union, and Wasatch formations of the region.

The succession and predicated interrelationship of the local Upper Cretaceous and early Eocene formations are shown by figure 2, which is also constructed to show in crude fashion the topographic features along the line of section A-B (figure 1) between the Crazy Mountains and

[2] 53. (See Bibliography, page 500.)
[3] 15.
[4] 30; 31.
[5] 90, pp. 6-7.

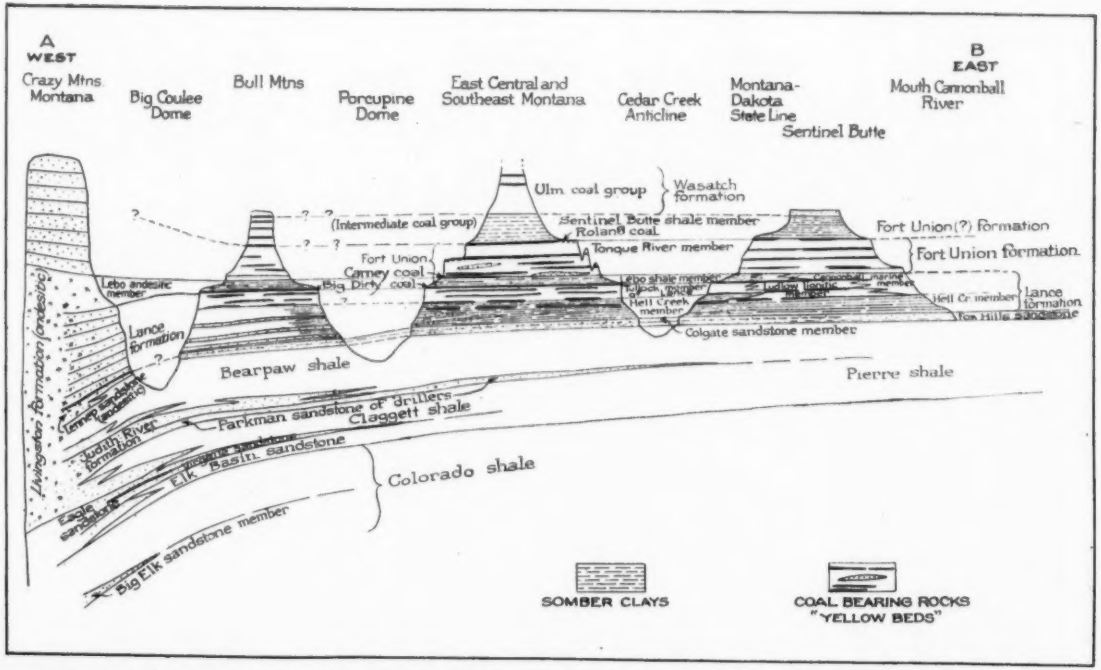


FIGURE 2.—*Succession and Interrelationship of Upper Cretaceous and early Eocene Formations of eastern Montana and of the Dakotas*

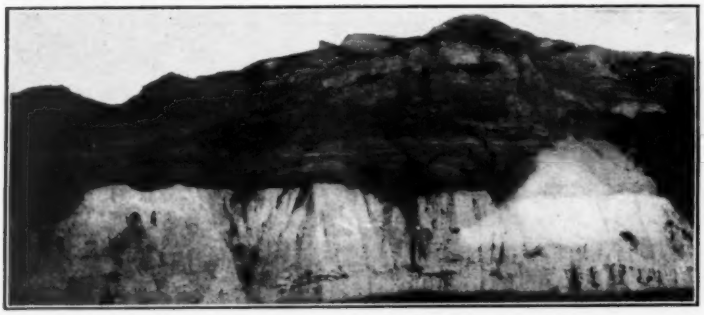


FIGURE 1.—LOWER PART OF HELL CREEK MEMBER OF LANCE FORMATION AND UNDERLYING COLGATE SANDSTONE MEMBER OF FOX HILLS NEAR GLENDIVE, MONTANA, SHOWING SLIGHT IRREGULARITY OF CONTACT

FIGURE 2.—HELL CREEK CLAYS, COLGATE SANDSTONE, AND BROWN LOWER MEMBER OF FOX HILLS EXPOSED ON DEVIL CREEK, 175 MILES NORTHWEST OF GLENDIVE, MONTANA

FIGURE 3.—BROWN LOWER MEMBER OF FOX HILLS, COLGATE SANDSTONE MEMBER, AND BROWN CHANNEL SANDSTONE AT BASE OF HELL CREEK MEMBER OF LANCE, NEAR MECAHA, MONTANA

Bismarck. The contrasting topographic expression of the somber and yellow post-Fox Hills units (see plate 24, figure 2, and plate 25, figure 4) are also indicated by figure 2. Figure 3 illustrates the control of formational thicknesses by structural features. In addition to present structure, it shows the degree of pre-Sentinel Butte or pre-Tongue River; pre-Lebo; and pre-Lance deformation of the Dakota sandstone, the datum planes used being respectively the base of the Sentinel Butte shale, or base of the Tongue River; the base of the Lebo; and the top of the Fox Hills, these corresponding approximately to sealevel at the time of their respective deposition.

As shown by figure 3, the post-Dakota formations in general grow thinner from west to east and from south to north, presumably showing a convergence of ancient drainage toward the Williston basin and Hudson Bay. The numerous local variations of thickness are also illustrated by table 1.

As shown by figure 2, the marine shale columns of the Colorado and Montana groups of eastern Montana contain sandstone tongues which extend successively farther to the east, ultimately encroaching strongly on the Great Plains trough in Lennep and Fox Hills time. In post-Fox Hills time alternating somber (topset swamp) and yellow coal-bearing floodplain deposits of fresh-water origin were laid down in eastern Montana as the coastal plain encroached eastward on the marine waters of the Williston basin, ultimately extinguishing this last remnant of the Interior Sea in post-Cannonball time.

LENNEP SANDSTONE

The Lennep sandstone is developed east of the Crazy Mountains in central Montana, and consists of dark-colored andesitic sandstone and shale, which are commonly dark brown en masse.[27] It contains thin coal beds in its upper part in the western part of the Lake Basin field,[28] and grades eastward, from fluviatile strata, into marine sandstones which intertongue with the Bearpaw shale. The top member of the Lennep is probably of fresh-water origin in its western outcrops, and is traceable eastward into brown marine sandstone, almost certainly equivalent to the brown lower sandstone of the Fox Hills.

FOX HILLS SANDSTONE

General statement.—The Fox Hills sandstone is at present classified as the uppermost formation of the Montana group and the youngest

[27] 84, pp. 746-752.
[28] 30, pp. 124-127.

formation of the northern Plains, undoubtedly of Upper Cretaceous age. It overlies the Pierre shale conformably, and commonly consists of a brown sandstone or sandy shale overlain by a white sandstone (see plate 23), both of which are of marine origin at the type locality of the formation in South Dakota.[29] [30] At several localities in South Dakota the top stratum of the Fox Hills consists of a sandstone containing abundant brackish-water shells mingled with typical Fox Hills species.[31] Local channeling at the base of this brackish-water bed has been noted at several localities, and lensing and cross-bedding are common features of the formation.[31]

The junior author and J. B. Reeside, Jr., have traced the outcrop of the Fox Hills westward from its type area in South Dakota into eastern Montana, localities of reported unconformity at the top of the Fox Hills[32] [33] [34] being visited en route. Three of the four angular unconformities reported as existing at that horizon were found to be misinterpreted instances of faulting, foreset bed development, or cross-bedding. The fourth angular break, reported to exist in section 32, township 7 north, range 61 east, Montana,[34] is not at that locality and could not be found. Its significance is consequently indeterminate.

Actual erosional channels in the top of the Fox Hills, filled by brown sandstone or carbonaceous shale, are, however, quite common (see plate 23) and have been often referred to.[35] [36] [37] Similar channels and cross-bedding are, however, equally abundant both within the Fox Hills and in the overlying strata to the top of the local geologic section, those at the top of the Fox Hills being relatively more conspicuous because of the white color of the Colgate sandstone member. Recurrence of channeling at the top of the Fox Hills might have great significance, especially if the Fort Union flora extended downward to the base of the Lance, but not into the Fox Hills, as was originally supposed. Now, however, since it is known that collections of leaves identified as Lance species[38] were actually obtained from the Colgate sandstone member of the Fox Hills, as described below, one principal reason for ascribing importance to post-Fox Hills erosion disappears. The lithologic similarity of the Colgate sandstone member to sandstones developed in the Hell Creek

[29] 58, pp. 419-427.
[30] 49, pp. 511-531.
[31] 78, pp. 174-179.
[32] 11, pp. 18-19.
[33] 47, pp. 43-44.
[34] 41, pp. 367-368.
[35] 78, p. 182.
[36] 10, pp. 194-195.
[37] 7, pp. 356-357; 8, pp. 829, 94*a*.
[38] 10.

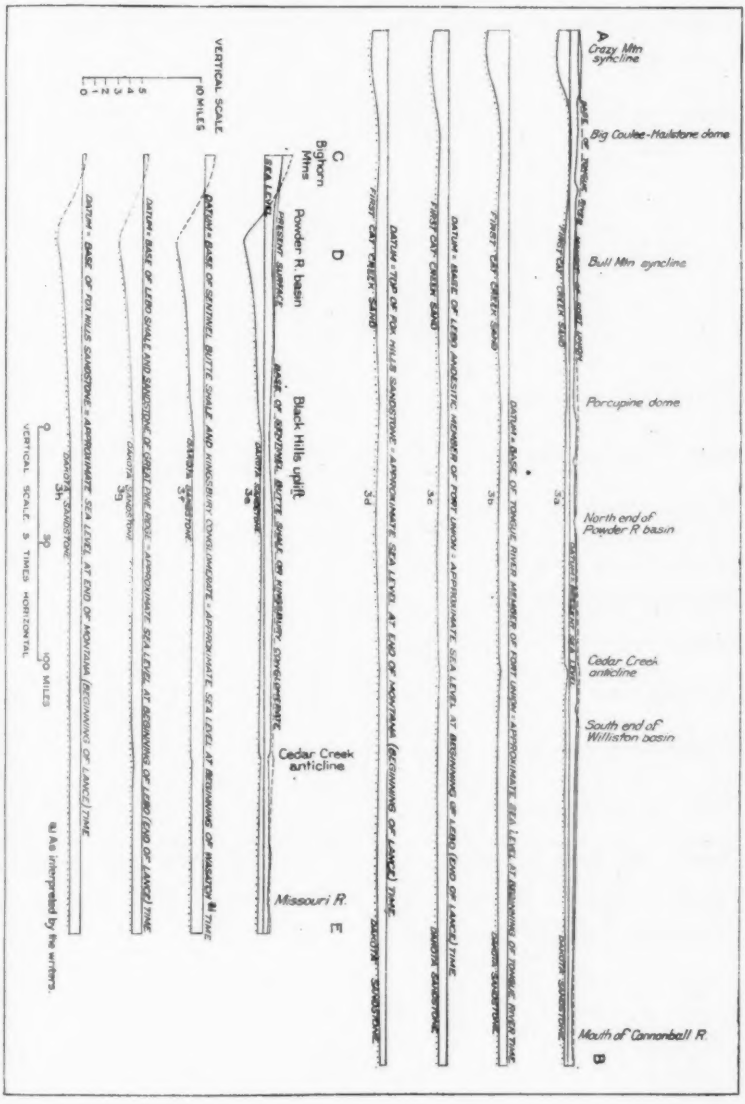

Crazy Mtn syncline
Big Coulee-Haulstone dome
Bull Mtn syncline
Porcupine dome
North end of Powder R basin
Cedar Creek anticline
South end of Williston basin
Mouth of Cannonball R.
B
DATUM = BASE OF LEBO ANDESITIC MEMBER OF FORT UNION = APPROXIMATE SEA LEVEL AT BEGINNING OF LEBO (END OF LANCE) TIME
DATUM = TOP OF FOX HILLS SANDSTONE = APPROXIMATE SEA LEVEL AT END OF MONTANA (BEGINNING OF LANCE) TIME
C
Bighorn Mtns
D
Powder R. basin
Black Hills uplift
Cedar Creek anticline
Missouri R.
E
VERTICAL SCALE
10 MILES
DATUM = BASE OF SENTINEL BUTTE SHALE AND HINSDALE? CONGLOMERATE = APPROXIMATE SEA LEVEL AT BEGINNING OF WASATCH? TIME
DATUM = BASE OF LEBO SHALE AND SANDSTONE OF GREAT ONE BEDS = APPROXIMATE SEA LEVEL AT BEGINNING OF LEBO (END OF LANCE) TIME
DATUM = BASE OF FOX HILLS SANDSTONE = APPROXIMATE SEA LEVEL AT END OF MONTANA (BEGINNING OF LANCE) TIME
VERTICAL SCALE 5 TIMES HORIZONTAL
100 MILES
a) As interpreted by the writers.

FIGURE 3.—*Cross-sections illustrating progressive Growth of Uplifts of eastern Montana and adjacent Areas*

TABLE 1.—*Thickness of Cretaceous-Eocene Transition Beds Within Local Areas of Eastern Montana, Northeastern Wyoming, and Western Dakota, as interpreted by the Writers*

	Fox Hills sandstone		Lance formation		Fort Union formation		Fort Union? formation	Wasatch formation
	Lower brown member	Colgate sandstone member	Hell Creek Member	Tullock member	Lebo andesitic (or shale) member	Tongue River member	Sentinel Butte shale member[6]	Ulm Coal group
Tullock Creek field, Montana[7]	75+	800		300	135–170	675±		
Crow Reservation, Montana[22]	50+	75–180	600–800	300–500	150–800	800+	500+	
Sheridan—Buffalo, Wyoming[8]	2000+				800–1000	800±	1100–2500	800±
Big Horn Basin, Wyoming[9]	?	—∞ 840–1800			2000–5600		1300+	
Elk Basin, Wyoming[23]	?	700?	—∞ 4300				—∞ 3200	
Northeast of Crazy Mountains[10]	100–460	900–2100			400–2100	4000+		
Bull Mountains[11]	50+	50+	500–1000	300+	150–300	800–1000	—∞ 750	
Garfield County, Montana[12]	20–75	20–50	550	150	125±	450+		
Glendive—Sidney, Montana[13]	0–50	30–120	350–500	90–160	200–250	730±	300+	
Poplar—Culbertson, Montana[14]	90		180±	75	280	650±	200±	
Scobey—Plentywood, Montana[15]	80		130±	40±	275	600±		

[6] Regarded as Wasatch by the writers.
[7] 68; 70; 24.
[8] 86; 28.
[9] 39.
[10] 84; 85; 5; 30.
[11] 101.
[12] 88; 23.
[13] 10; 81; 59.
[14] 89; 3.
[15] 15; 22; 57; 2; 72.

TABLE 1—Continued

	Fox Hills sandstone		Lance formation		Fort Union formation		Fort Union? formation	Wasatch formation
	Lower brown member	Colgate sandstone member	Hell Creek member	Tullock member	Lebo andesitic (or shale) member	Tongue River member	Sentinel Butte shale member	Ulm Coal group
Williston—Minot, North Dakota[16]	40±		380–640			550–800	550±	
Sentinel Butte, North Dakota[17]	50±		520±			700±	400±	
South Dakota and Canonnball area, North Dakota[18]	75–150		400–525	Ludlow and Cannonball 300–350	500±	420±		
Ekalaka—Baker, Montana[19]	0–75	60–75	400–500	275–350	150—			
Terry, Montana[24]	75±		500±	250–300	150–340	850+		
Miles City, Montana[20]	75±		500±	300±	200–350	400+		
Broadus, Montana[25]	75		300–400	300	100+	400–600	500+	
Little Powder River—Gillette area, Wyoming[26]	75–200		400	1300–2000	100–200	500–800	900+	150+
Pumpkin Butte area, Wyoming[21]	590?	100±	2000	1200	2000	Unconformable overlap	700±	1800+

[16] 13; 38; 91.
[17] 50; 19.
[18] 53; 54; 32; 99; 11.
[19] 1; 10; 33.
[20] 14.
[21] 97; 98.
[22] C. H. Wegeman and R. W. Howell: Unpublished data.
[23] 100; C. J. Hares: Unpublished data.
[24] 69; 37: Unpublished data.
[25] Unpublished data.
[26] 21; 83: Unpublished data

member of the Lance; the large number of marine invertebrates common to the Fox Hills or Pierre and Cannonball[39] faunas; and the occurrence of a Fort Union flora in strata of the Edmonton formation,[40] apparently of Bearpaw or Fox Hills age, are additional reasons for believing that no important hiatus exists between the Fox Hills and overlying beds, in Dakota areas at least.

Colgate sandstone member.—This term is here redefined and applied to the conspicuous, white, upper sandstone of the Fox Hills, typically developed between Colgate station and Glendive, Montana, and extensively exposed along the Cedar Creek anticline and elsewhere in eastern Montana (see plate 23). As originally defined,[41] the Colgate was considered to be the basal member of the Lance, and was said to consist of two 75-foot sandstone units exposed in Iron Bluff, near Colgate station, and a top white sandstone, 35 feet thick, exposed near by. Actually this 35-foot white sandstone is the upper (Colgate) member of the Fox Hills and forms the top part of the lower 75-foot sandstone of Iron Bluff, its white color being masked in the Iron Bluff exposure by ferruginous matter leached from the overlying brown sandstone of the Lance. In addition to fossil leaves, the Colgate sandstone, as here redefined, contains abundant casts of *Halymenites major* in exposure along the Cedar Creek anticline, and is gradational into the underlying marine strata on Little Beaver Creek, south of Baker. The Colgate is strikingly developed along the Missouri between Hell Creek and Mussellshell River (see plate 23), consisting there of 15 to 50 feet of white sandstone, resembling its type development in lithology, though probably of fresh-water rather than of strand accumulation. The presence of the Fox Hills in the Yellowstone Valley west of the Cedar Creek anticline is indicated by artesian wells. West of Forsyth, however, where is reappears, the lower part of the Fox Hills is overlain by a massive, persistent, fluviatile sandstone, believed to be the one forming Pompey's Pillar,[42] which is traceable westward into the base of the white Lance sandstones overlying the Lennep in central Montana. That the fluviatile basal sandstone of the Lance of central Montana is stratigraphically equivalent to the Colgate sandstone and to the upper white sandstone of type Fox Hills the writers feel confident, although this has not been conclusively demonstrated by continuous tracing.

In contrast with the brown sandstone of the lower part of the Fox Hills, and some brown sandstones of the Judith River formation, which

[39] 54, 80.
[40] 7, p. 373.
[41] 10, pp. 194-195.
[42] 31, p. 128.

are largely composed of material derived from weathered granitic rocks, and stained by ferruginous alteration products, the typical Colgate sandstone consists of angular quartz and feldspar grains mixed with interstitial material resembling the bentonitic derivations of volcanic tuffs.

LANCE FORMATION

General statement.—Near the Crazy Mountains the Lance consists of several hundred feet of massive light-colored fluviatile sandstones interbedded with minor amounts of greenish clay. Near the Bull Mountains[43] and near Hardin[44] the Lance strata overlying the basal sandstone referred to in the discussion of the Colgate sandstone are divisible into an upper member (Tullock), consisting of yellow coal-bearing rocks, and a lower member, consisting principally of massive fluviatile sandstones. Farther east, in the vicinity of Hell Creek, the rocks of the lower member consist principally of somber badland clays, to which the name Hell Creek member is here applied.

Hell Creek member.—The Hell Creek member (of the Lance formation) as here defined is typically exposed on Hell Creek, Garfield County, Montana, and is equivalent to the "Hell Creek beds" and "lignite beds" of Brown,[45] occupying the interval between the Fox Hills sandstone and the yellow Tullock member of the Lance. The Hell Creek member consists of somber clays (see plate 23), probably accumulated in topset swamps of a great delta, and fluviatile sandstones, the latter being more numerous and conspicuous toward the southwest. Remains of a few small mammals have been found in these sandstones.[46] Dinosaurs, including Triceratops, are numerous below the "A" lignite, which marks the base of Brown's "lignite beds," but probably have not been found above that horizon. In addition to fresh-water invertebrates, the upper beds of the Hell Creek member have yielded a shell identified as the brackish-water form *Corbicula subelliptica* and remains of a shark of the marine genus Lamna.[47] Specimens taken from the brown channel sandstones at the base of the member consist of granitic materials similar to those composing the lower part of the Fox Hills, save that they are less weathered and less stained by ferruginous alteration products. The normal somber sandstones of the Hell Creek member of the Lance doubtless owe their dark color to "humic" acid stain, and consist of material derived from relatively unweathered garnetiferous metamorphic rocks as

[43] 101.
[44] 68; 70.
[45] 8, pp. 829-835.
[46] 8, p. 840; 56.
[47] 8, pp. 837, 842.

well as from granitic rocks. The Hell Creek and overlying strata are markedly calcareous in contrast with the brown member of the Fox Hills and older rocks, which are relatively free from lime. The contrasts in lithology between the Colgate and Lance on the one hand and the lower member of the Fox Hills on the other are believed to indicate somewhat different sources of sediment, probably resulting from a post-lower Fox Hills elevation in the Cordilleran region to the west.

Tullock member.—The Tullock member of the Lance, named by Rogers and Lee[48] from Tullock Creek, southwest of Forsyth, characteristically presents a marked contrast to the Hell Creek member in its yellow color, uniformity of bedding, and topographic expression, the Tullock standing in a steep escarpment rising above lowlands or badlands developed on the Hell Creek clays (see plate 25, figure 4). The Tullock consists of a fine-grained, calcareous, yellow, sandstone, or sandy shale, and contains numerous thin coals or carbonaceous beds. Thin-bedded calcareous ripple-marked sandstones of great areal extent also feature the member and are responsible for its scarp-forming habit. The numerous carbonaceous beds of the member give a striped appearance to its outcrop, and south of Poplar these carbonaceous beds commonly display a maximum thickness adjacent to channel sandstones showing marked scouring beneath them. The Tullock is recognizable in the Bull Mountain field, is a well-marked unit in east central Montana, and has several times been mistaken for the Tongue River member of the Fort Union.[49] East of the Powder River-O'Fallon Creek divide and along the Cedar Creek anticline it is still recognizable, though thinner and lithologically more like the underlying Hell Creek member and overlying Lebo shale. The soft yellow sandstones and light-colored sandy shales of the Tullock, like those of the Tongue River "yellow beds," are in general fine grained and, in the writers' opinion, owe their color to thorough oxidation and leaching under conditions of floodplain deposition.

Ludlow lignitic member.—The Ludlow lignitic member of the Lance is typically developed near Ludlow, South Dakota,[50] and in that vicinity is similar lithologically to the Tullock member of the Lance and to the Tongue River member of the Fort Union, although it is prevailingly dark colored near Marmarth, North Dakota. As shown in figure 2, the Ludlow member of the Lance is equivalent to the Lebo member of the Fort Union of Montana, plus the Tullock member of the Lance and the "lignitic beds" of Brown, which are that part of the Hell Creek member of the Lance lying above the "A" lignite zone.

[48] 68, pp. 29-34.
[49] 8, pp. 835-836; 43, p. 199.
[50] 99, pp. 18-20.

FIGURE 1.—STRATA OF TONGUE RIVER MEMBER OF FORT UNION EXPOSED NEAR LEE, MONTANA
(Bass, U. S. Geological Survey)

FIGURE 2.—CONTACT OF LEBO SHALE AND TONGUE RIVER MEMBERS OF THE FORT UNION FORMATION NEAR TERRY, MONTANA

FIGURE 3.—CHANNEL SANDSTONE IN UPPER PART OF HELL CREEK MEMBER OF LANCE SOUTH OF WOLF POINT, MONTANA

FIGURE 4.—SOMBER SANDSTONE, UNIO-BEARING BED, AND FORESET BEDS IN LEBO SHALE SOUTH OF WOLF POINT, MONTANA

Cannonball marine member.—The Cannonball marine member of the Lance is at present known only in the Missouri Valley in North and South Dakota, and is stratigraphically equivalent to the Ludlow lignitic member of the Lance, into which it merges westward.[51] The Cannonball consists of dark sandy shale, with minor amounts of dark yellow or gray sandstone, and contains an abundant marine fauna largely descended from that of the Fox Hills.[52] The westernmost collection of this marine fauna was obtained within 100 feet stratigraphically of the T Cross lignite, near Haley, North Dakota, and oyster-shell beds representing the western limits of the marine Cannonball invasion have been found above the T Cross lignite, near Marmarth and Yule, North Dakota.[53]

FORT UNION FORMATION

General statement.—The term Fort Union "group" was originally proposed by Meek and Hayden[54] in 1861. They stated that it "occupies the country around Fort Union [now Buford, North Dakota], extending north into the British possessions to unknown distances; also southward to Fort Clark (on the Missouri, 50 miles above Bismarck). Seen under the White River group on North Platte River above Fort Laramie. Also on west side of the Wind River Mountains." Also it "occupies extensive areas of country in Nebraska (territory), and has been seen beneath the White River group at several distance localities." A confused use of the term Fort Union has naturally resulted. According to the interpretation of the writers, the term Fort Union formation should be restricted to the Lebo andesitic (or shale) member and the Tongue River member, although the Sentinel Butte shale is classed as Fort Union (?) by the U. S. Geological Survey.

Lebo andesitic (or shale) member.—The Lebo member of the Fort Union is typically developed on Lebo Creek, Montana, northeast of the Crazy Mountains,[55] and consists of a tongue of andesitic rocks resembling the Livingston formation[56] and the Lennep sandstone. The presence of andesitic or volcanic material in the Lebo is still evident in the Bull Mountains and east of the Porcupine Dome,[57] but in its eastern exposures the member consists principally of dark clays and fluviatile sandstones (see plate 24, figure 4), and is called the Lebo shale member within these

[51] 54.
[52] 80; 54.
[53] 54, p. 540, 33.
[54] 58.
[55] 84, p. 746.
[56] 101, pp. 24-27; 95; 96.
[57] 68, pp. 170-172; 69, pp. 165-172.

eastern fields.[58] In the Miles City coal field[59] the Lebo is represented by that portion of the "somber beds" above the "C" coal. It is also well developed west of Miles City and south of the Yellowstone, growing thicker and more evenly bedded as it is traced southward into the upper part of the lower member of the Sheridan field,[60] eventually developing into the Great Pine Ridge sandstone fan of the Pumpkin Butte area of Wyoming,[61] which Wegemann calls Fort Union, and indicates is probably overlapped by Wasatch (Kingsbury conglomerate). East of Miles City some yellow strata and coals are interbedded with the dark shales of the Lebo (see plate 24, figure 2), but the member retains its prevailingly dark tone as it is traced eastward to the Glendive anticline, the Lebo there consisting of the beds above the "lowest persistent" lignite of Calvert,[62] extending upward from the A lignite of the Sidney lignite field[63] to about 40 feet above bed D. In the vicinity of Plentywood and Scobey the Lebo extends from the base of the D,[64] or Redstone coal bed, to about 60 feet above the Richardson[65] lignite.

The thick coal bed which commonly marks the base of the Lebo often contains many partings of volcanic ash and carbonaceous sandstone. This coal, called the Big Dirty bed in the Bull Mountain field,[66] was called beds U and NN in the Little Sheep Mountain field,[67] bed C in the Miles City field,[68] and the "lowest persistent lignite" in the western part of the Terry field.[69] It is closely equivalent to the "lowest persistent lignite" zone mapped along the Cedar Creek anticline, which in turn is identical with the T Cross lignite of the Ludlow lignitic member of the Lance of North and South Dakota. Inasmuch as the brackish-water beds near Marmarth lie between the T Cross lignite and the base of the Tongue River member of the Fort Union,[70] the upper marine beds of the Cannonball are of the same geologic age as type Lebo, which on Fish Creek, Montana,[71] [72] contains a considerable Torrejon mammalian fauna.

Tongue River member.—The Tongue River member of the Fort Union

[58] 69, pp. 165-172.
[59] 14.
[60] 86, pp. 128-129.
[61] C. H. Wegemann: Personal communication, 97, 98.
[62] 10.
[63] 81.
[64] 15.
[65] 2, pp. 299-300.
[66] 101, pp. 35-36.
[67] 69.
[68] 14.
[69] 37, pp. 231-232.
[70] 54, pp. 539-540.
[71] 25; 26.
[72] 84, pp. 755-756.

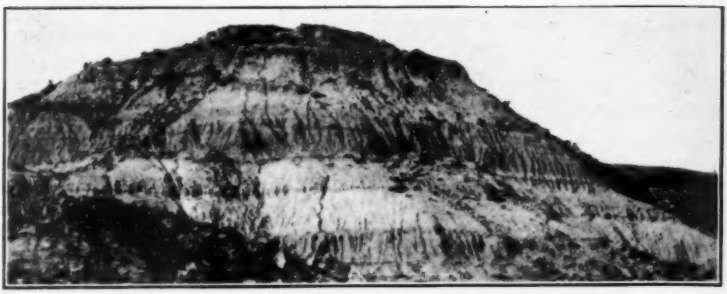


FIGURE 1.—EXPOSURE OF SENTINE BUTTE SHALE SOUTH OF AMIDON, NORTH DAKOTA

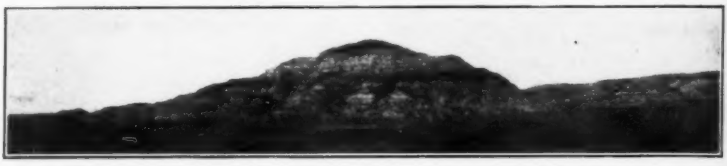


FIGURE 2.—SENTINEL BUTTE SHALE EXPOSURE NEAR SULLY SPRINGS, NORTH DAKOTA

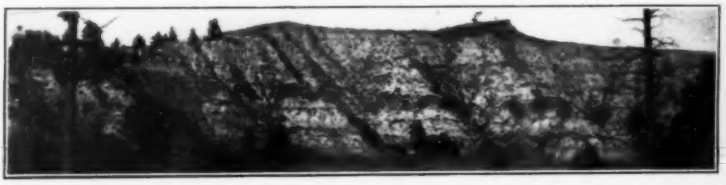


FIGURE 3.—YELLOW STRATA OF TONGUE RIVER MEMBER NEAR TULLOCK CREEK, MONTANA
(Rogers, U. S. Geological Survey)

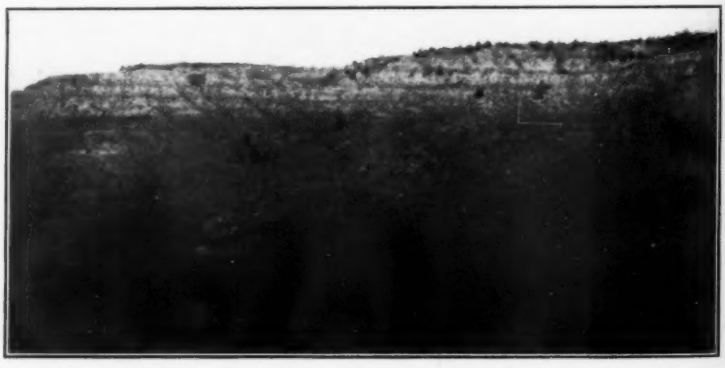


FIGURE 4.—ESCARPMENT OF TULLOCK MEMBER OF THE LANCE FORMATION NEAR FORSYTH, MONTANA

consists of yellow or light-colored strata containing massive sandstones and numerous thick coal beds. It is well exposed along Tongue River between Carneyville, Wyoming, and Brandenberg, Montana, and along the Yellowstone between Burns, Montana, and Buford (Fort Union), North Dakota. It is also exposed in the Missouri Valley above Fort Clark, North Dakota. The top of the member as here defined is placed beneath bed K of the Sidney field,[73] bed F of the Sentinel Butte field,[74] and the Roland coal bed of the Sheridan field. The base of the member is placed beneath the light-colored, coal-bearing rocks which characteristically form a marked clinker-capped escarpment rising above lowlands or badlands developed from the somber Lebo shale (plate 24, figure 2). The Lebo-Tongue River contact, though clean cut in the average exposure, does not, however, occur at a single plane when traced over great distances, but rises or falls in the geologic column by the intertonguing of the yellow Tongue River and somber Lebo strata. Massive channel sandstones are numerous both in the Tongue River member (plate 24, figure 1) and at its base, and channeling beneath these sandstones is a common feature.[75] A few teeth and bones of mammals resembling those of the Lebo have been obtained from the Tongue River member[76] [77] in Montana and Dakota areas, and it contains the brackish-water fossil *Corbula mactriformis* in North Dakota.[78]

FORT UNION (?) FORMATION—SENTINEL BUTTE SHALE MEMBER

The Sentinel Butte shale, classed as Fort Union (?) by the U. S. Geological Survey, though regarded as Wasatch by Hares[79] and the writers, is typically developed at Sentinel Butte, North Dakota (plate 25, figure 2), and consists of dark clay shales[80] resembling those of the Hell Creek and Lebo in topographic expression and to some extent in appearance.

The Sentinel Butte shale is essentially equivalent to the Intermediate coal group of northern Wyoming,[81] plus the Roland coal bed, and to the lower part of the Kingsbury conglomerate,[82] which overlaps[83] on the granite core[84] of the Big Horn Mountains. This unconformable overlap

[73] 81.
[74] 50.
[75] 54, pp. 538-547; 24.
[76] 54, p. 538.
[77] 84, p. 756.
[78] 46, p. 3; 80, p. 12; 33.
[79] C. J. Hares: Unpublished manuscript.
[80] 50, pp. 18-21.
[81] 86, p. 130.
[82] C. H. Wegemann: Personal communication; 86, p. 131.
[83] 20, pp. 60-62.
[84] 86, p. 130.

Wegemann[85] regards as marking the base of the Wasatch, indicating the Wasatch age of the Sentinel Butte, an assumption supported by the physical relationships brought out by figure 2.

In northern Wyoming and southern Montana, and perhaps in Dakota areas as well, the base of the Sentinel Butte shale is marked by the Roland coal bed, which in thickness, persistence, and general genetic relationships resembles the Big Dirty coal of the Lebo.

WASATCH FORMATION—ULM COAL GROUP

In southern Montana and in the Powder River basin of Wyoming the Sentinel Butte shale (Intermediate coal group) is conformably overlain by yellow coal-bearing strata belonging to the Ulm coal group,[86] which is correlated[87] with the Wasatch beds of the Pumpkin Butts, Wyoming.[88]

It is believed by the writers that strata representative of both Sentinel Butte shale and Ulm coal group may be included in Fort Union as mapped in the Red Lodge coal field,[89] and it is possible that one or both of them may be represented in beds now classed as Fort Union in the Bull[90] and Crazy Mountains.[91]

SUMMARY

After extensive field examinations covering Montana, Dakota, and some Wyoming areas, the writers feel convinced that the Plains regions of these States were loci of practically continuous deposition from basal Colorado into Wasatch time, the Lance and Fort Union formations constituting a transition group between the Cretaceous Fox Hills and the Eocene Wasatch. With this interpretation all evidence now available is in harmony.

In contrast with rhythmic depression and continuous deposition in the negative Plains areas, periodic uplift in the positive mountain areas to the west is indicated by angular unconformities in their flanking, upturned, sedimentary rocks. Thus the Kingsbury conglomerate, as suggested by Wegemann,[92] apparently marks the base of the Wasatch, and represents the coarse phase of the Sentinel Butte shale where it overlaps on the Bighorn fold. Similarly, the pre-Fort Union unconformity of the Big Horn Basin is apparently an overlap representing part of Lebo time,

[85] 98, p. 60.
[86] 86, pp. 130-131.
[87] C. H. Wegemann: Personal communication.
[88] 98.
[89] 100, pp. 92-107.
[90] 101.
[91] 84.
[92] 98, p. 60.

the Lebo carrying a Torrejon fauna and being equivalent to the upper part of the Cannonball marine member of the Lance.

The absence of any great diastrophic break in the northern Plains section between the Fox Hills and the Wasatch is indicated (1) by the uninterrupted rhythm of earth movements shown in figure 2; (2) by the apparent survival of a restricted Fox Hills fauna in a relic sea in the Williston Basin at least as late as Cannonball time, and (3) by the essential identity of the Lance, Fort Union, and Wasatch floras, and by the presence of plants identified as Lance species in the Colgate member of the Fox Hills, or below the previously supposed Cretaceous-Eocene unconformity.

The assignment of the Lance and Fort Union transition beds to Cretaceous or Eocene will depend on the type section against which a comparison is made. On the basis of diastrophic and other natural relationships found in eastern Montana and northern Wyoming, a worker in the region would select the Tongue River-Sentinel Butte contact, or base of the Kingsbury conglomerate as the local Cretaceous-Eocene boundary.

These conclusions of the writers as to the completeness of the northern section and the natural basis for its division between Cretaceous and Eocene are in accord with statements published by the Montana State Bureau of Mines[93] and South Dakota Geological and Natural History Survey.[94] They are also in consonance with opinions recently expressed by Schuchert,[95] and are partly concurred in by Matthew.[96] Objections to these views have been summarized by Cross and Knowlton.[97]

Whatever scheme of formational classification is ultimately adopted, it is obvious from facts already presented, and summarized in figure 2, that a rational classification of the marine deposits of the northern area will not coincide exactly with a classification framed according to diastropic movements, as the pre-Lebo uplift took place about the middle of Cannonball time, and it is probable that an uplift of the mountain areas occurred about the middle of type Fox Hills time.

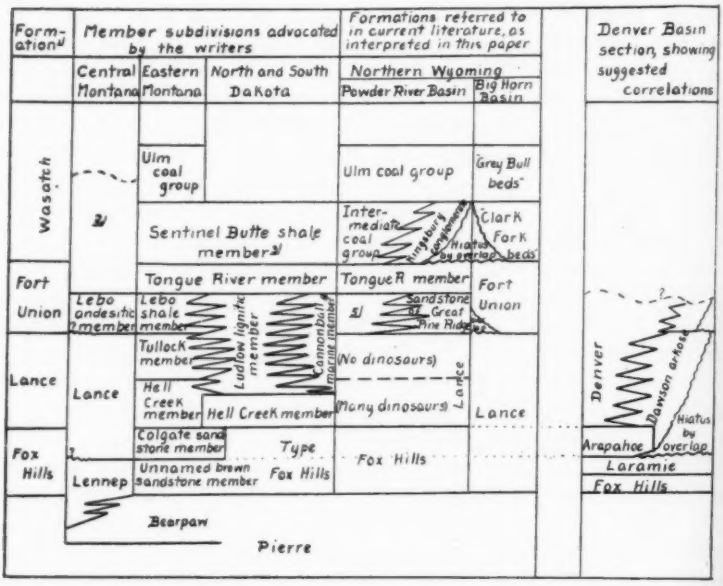
Part II. Relation of the northern Plains and Denver Basin Sections

No discussion of the Cretaceous-Eocene boundary problem of the Rocky Mountain region is complete without reference to the Denver

[93] 12, pp. 25-26.
[94] 94, p. 7, 94*a*.
[95] 73.
[96] 55.
[97] 17.

Basin section, which has figured so largely in past discussions of the problem, the post-Laramie hiatus of the Denver region[98] having been adopted as the Cretaceous-Eocene contact by the U. S. Geological Survey. For this reason the writers venture tentative correlations of the northern Plains and Denver Basin sections, though their lack of personal familiarity with the geology of the Denver Basin renders such suggestions

TABLE 2.—*Showing proposed Subdivision and Correlation of transition Beds*



1. As interpreted by the writers.
2. Fort Union of Stone and Calvert (84).
3. Classed as Fort Union (?) by the U. S. Geological Survey.
4. Classed as Lance by the U. S. Geological Survey.
5. Fort Union of Wegemann (98).

valuable only as they may serve as useful hypotheses to be tested by further field work.

In the Denver Basin the Pierre shale is conformably overlain by a marine sandstone assigned to the Fox Hills (see table 2), and this in turn by the coal-bearing Laramie formation. The Arapahoe conglomerate, constituting essentially the basal bed of the andesitic Denver formation and equivalent Dawson arkose, overlies the Laramie without

[98] 17; 44; 45; 92.

observable discordance, but is supposed to be separated from it by a great time break and diastrophic movement.

The pre-Arapahoe, post-Laramie uplift in the Denver Basin, in the writers' opinion, is probably to be correlated with the earth movement reflected in the abrupt lithologic change between the lower brown phase of the Fox Hills and the overlying Colgate sandstone member of eastern Montana. In both northern Plains and Denver Basin the movements correlated took place between the Fox Hills and Triceratops faunas, and the igneous activity which followed the post-Laramie movement of the Denver Basin may have been paralleled by volcanic outbreaks in the north as suggested by the lithology of the Colgate sandstone member. Being so nearly simultaneous, it seems logical to assume that the same general movement found expression in the two localities. This interpretation renders the Laramie of the Denver Basin essentially equivalent to the coal-bearing phase of the Lennep sandstone—that is, to the upper part of the lower member of Fox Hills—the Fox Hills of the Denver Basin corresponding to the oldest part of the type Fox Hills. Pre-Arapahoe or pre-Colgate uplift was apparently paralleled by further depression in the northern Plains basins, and consequently the deposition of type Fox Hills continued during the development of the adjacent mountain erosional unconformity, just as the deposition of the Cannonball marine member of the Lance continued across the pre-Fort Union unconformity of the Bighorn Basin.

In one respect the suggestions made by the writers accord closely to those of Cross and Knowlton,[99] in that all consider the plant-bearing Colgate sandstone of the Glendive area to be above the post-Laramie hiatus. There is, however, a difference of opinion as to the probable magnitude of the post-Laramie break.

It must be admitted that the writers' correlations of the Laramie with the Lennep of central Montana and of the Fox Hills of the Denver Basin with the older part of type Fox Hills are suggestive only. Evidence proving or disproving the proposed correlations is yet to be obtained, and some general agreement must be reached as to the position of the Cretaceous-Eocene boundary in a standard section before any final and thoroughly satisfactory conclusion and age classification can be made.

[99] 17.

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CONTACT METAMORPHISM AT BINGHAM, UTAH[1]

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INTRODUCTION

It was held not long ago that the igneous metamorphism of a limestone involved no notable additions of material. This view is now generally abandoned, and it is recognized that the most far-reaching changes may

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take place involving very large additions of silica, as well as iron and other metals. It is also recognized that the limestone usually suffers a loss not only of carbon dioxide, but also of calcium oxide and sometimes other constituents. This has been abundantly proved by changes which alter a pure limestone into a heavy iron-lime silicate, such as andradite, and it has been shown that the volume, aside from pore space, remains substantially the same.

In case of an impure limestone the difficulty is greater because the average composition of the bed is rarely known and the exact additions and subtractions that have taken place remain more or less obscure.

My attention was first called to the metamorphism of the limestone at Bingham, Utah, some twenty-three years ago, when I first visited the mining district in the company of Mr. J. M. Boutwell, then of the U. S. Geological Survey.

In the thorough and detailed report on the district by Boutwell and Keith[2] it was suggested that additions of silica and magnesia have taken place during metamorphism. Although the relations shown were quite striking, the materials analyzed were specimens, and therefore no far-reaching conclusions could be drawn from them.

Later the geological conditions were summarized by a U. S. Geological Survey publication describing the ore deposits of Utah.[3]

Very recently the subject of metamorphism at Bingham has been treated by A. N. Winchell.[4] In this paper the transition rocks between limestone and sandstone are described. The lime-silicate rocks are proved to have originated from limestones. The fact that additions of material have taken place during metamorphism is stressed. It is shown that the unaltered and the metamorphosed limestones differ little in porosity. The average porosity of the nine specimens of the former is 3.7 per cent, the average porosity of eight specimens of partly altered limestones is 5.9 per cent, and the same relation for six specimens of completely metamorphosed rocks is 3.3 per cent. The evidence shows that a given bed of limestone can be converted into lime-silicate rock with no important change of volume, as the thickness remains unchanged. It is believed, therefore, that the change to silicates has occurred with no important change of volume.

The author concludes that the processes of silication and elimination of free carbon occurred at temperatures from 700° centigrade to 1,100°

[2] J. M. Boutwell and Arthur Keith: Prof. Paper 38, U. S. Geol. Survey, 1905, p. 184.

[3] B. S. Butler, G. F. Loughlin, and V. C. Heikes: The ore deposits of Utah. Prof. Paper 111, U. S. Geol. Survey, 1920, pp. 340-361.

[4] A. N. Winchell: Petrographic studies of limestone alterations at Bingham. Trans. Am. Inst. Min. and Met. Eng., New York meeting, 1924, pp. 16.

centigrade. The introduction of carbonates in veinlets in the limestone continued at lower temperatures and may, in fact, have been caused by meteoric waters. The main ore deposits were formed at lower temperatures. Silication is confined to the limestone beds and is not found in the fissure veins. With this last statement the present writer is not in complete agreement, for the Yampa vein (at the base of the Yampa limestone) contains both amphibole and garnet in places. This is, however, mainly a copper-bearing vein, while in the fissure veins and replacement deposits, which carry lead predominantly and are believed to have been formed at somewhat lower temperatures, there are no lime silicates at all, but only more or less of silicification and carbonatization.

The present Investigation

The opportunity for the present investigation arose in connection with a lawsuit between the Utah Apex Mining Company and the Utah Consolidated Mining Company, which owned adjoining claims in the upper part of Carr Fork.[5] During this legal contest, which involved questions of the so-called law of the apex, it became necessary to study the conditions surrounding the origin of the ore deposits and to examine in detail the processes of metamorphism which the rocks had suffered. It was thought desirable to establish the content of the fresh and altered rocks in silver, lead, copper, iron, and sulphur. For this purpose many of the cross-cuts in the mines which exposed beds of limestone or quartzite were sampled according to the methods of mine sampling of large ore bodies. These beds dipped about 30 degrees northward, and the cross-cuts, therefore, extended approximately north and south. A groove sample was cut across the whole formation, say across the Yampa limestone—that is, a continuous groove was chiseled out with hammer and moil, the furrow being about 4 inches wide and 1 inch deep. The sampling was divided into 10 feet units horizontally, each sample weighing from 30 to 50 pounds. A series of samples were thus obtained across the bed; if the bed was 200 feet thick, the horizontal distance would be about 400 feet, and this would be represented by 40 samples. The samples were duly quartered, reduced and assayed.

Realizing that interesting results might be obtained by analyzing these cross-cut samples, composite samples were prepared by taking one gram from each assay sample and thoroughly mixing them, the composites being finally quartered down to quantities suitable for analyses. The

[5] For account of this lawsuit, see Orrin P. Peterson, Some geological features and court decisions of the Utah Apex-Utah Consolidated controversy, Bingham district. Trans. Am. Inst. Min. and Met. Eng., New York meeting, February, 1924, no. 1341 M.

complete analyses were not required for the purpose of the sampling, but I was fortunate in later obtaining a grant from the Bache Fund of the National Academy of Sciences to defray the cost of the chemical work. The analyses were made by Prof. L. F. Hamilton, of the Massachusetts Institute of Technology.

I believe this is probably the first time that analyses have been made from samples of wide beds obtained by these laborious and expensive methods, and the results, I am confident, are unusually accurate and reliable. The cost of the sampling alone was probably about $2,000.

Generally speaking, the assays in the unaltered rocks proved blanks, while those of altered rocks contained more sulphur and iron and frequently traces or small amounts of copper, lead, and silver. It should be added that the cross-cuts sampled were outside of the ore deposits, and in the rare cases, where a small vein or other deposit or a dike was met, such a sample was discarded in the composites here used.

Geological Features at Bingham

It is well known that Bingham or West Mountain is one of the most important mining districts in the United States. The total production of gold, silver, copper, lead, and zinc is now not far from a value of $500,000,000 and the annual production in 1919 and 1920 approximated $27,000,000. The larger part of the output was derived from the disseminated ores in the open workings of the Utah Copper Company.

The ores are contained in replacement deposits in limestone, in veins, in disseminations in quartzite, and in disseminations in monzonite porphyry. The latter, represented by the Utah Copper property, have been enriched by chalcocite and covellite of supergene origin. Contact metamorphic ores of normal type with abundant silicates are present, but not abundant or important.

Briefly, the geological relations are as follows:

The predominant sedimentary rocks consist of about 8,000 feet of quartzite of Pennsylvanian (Upper Carboniferous) age, with several intercalated limestone beds or lenses. The beds are folded and faulted in a complex manner.

This series is intruded by irregular stocklike bodies, dikes, and sills of monzonite porphyry, which in large degree have suffered a hydrothermal alteration. The total area occupied by the intrusion is not large, probably less than two square miles.

The Limestones

It is not always easy to correlate the various limestone lenses. Besides several minor beds, there are the Jordan, Commercial, Yampa, and

Highland Boy limestones, which, from an economic point of view, are the most important. The present paper deals with the Yampa and Highland Boy limestones as exposed in the Utah Apex and in the Utah Consolidated mines. The Yampa is the upper of the two and is well exposed in the upper part of Carr Fork. Its average thickness is 200 feet, and it dips at angles of 17 degrees to 25 degrees toward the north. In the deeper part of the mines this and accompanying quartzite beds make a sharp bend and acquire a steep dip. The Yampa limestone in its normal state as exposed in the underground workings is a black, dense rock, which often emits a fetid odor when struck with a hammer. It is very uniform, except that some minor quartzite beds are embedded in it near the top. The beds just above the Yampa limestone are calcareous quartzite, but in most cases the upper limit of the limestone is quite clearly marked. The limestone is an impure variety, with much silica and little magnesia.

Toward the west beyond the samples here investigated the Yampa limestone turns into a calcareous quartzite. Within the territory here discussed its thickness is very uniform and it contains few quartzite beds.

About 200 feet below the Yampa lies the Highland Boy limestone. This is equally well exposed in many workings and when unaltered has the same black color and fine-grained texture.

The Highland Boy limestone is likewise uniform in the territory here discussed, but to the southwest, like the Yampa, it tends to become thinner. In its unaltered state it is a black, fine-grained rock entirely similar to the Yampa and the bed is usually about 200 feet thick. It is not so uniform in composition as the Yampa, for in its upper part it contains at least two beds of quartzitic calcareous rock. It is remarkable that in spite of this the average composition of the Highland Boy limestone is almost exactly identical with that of the Yampa.

The Metamorphism

Ascending Carr Fork, the Yampa limestone is first observed in the gulch about one and one-fourth miles west of Bingham Canyon town, and it continues west for about 3,000 feet, all of the part exposed being white and metamorphosed. The Highland Boy limestone is first seen farther up at the Highland Boy mine, and it is only exposed on the surface for about 1,200 feet; all of this exposure is also white, metamorphosed rock. The black Yampa limestone is found underground in the workings of number 7 tunnel, Utah Consolidated mine, where it is extensively exposed. It is also seen in the deeper workings of the Yampa mine and on the main tunnel level of the Utah Apex mine, still farther east. The

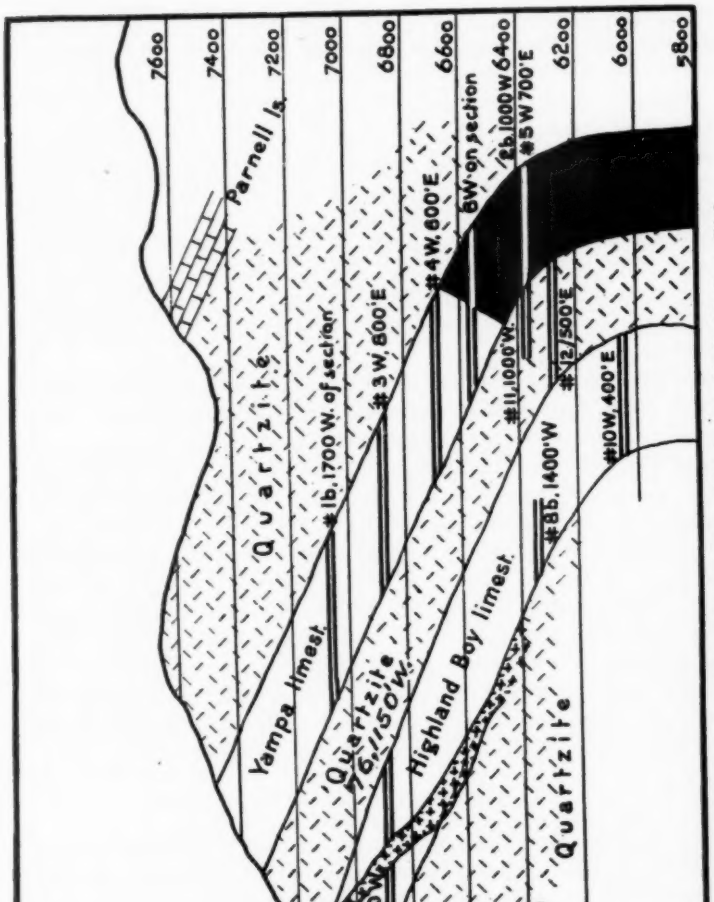

FIGURE 1.—*North-south Section 100 Feet West of Utah Apex Shaft, Bingham, Utah*

In this section the Highland Boy limestone is altered (white) throughout. The Yampa limestone is unaltered (black) in the lower part only.

contact of black and white limestone has a strong slant downward till near the Utah Apex shaft on the main tunnel level. From this level the contact dips steeper, apparently parallel to the Petro fissure, and is found actually farther west in the deep workings of the Utah Consolidated mine on number 13, 14, and 16 levels.

The general relations are shown in figure 1. On the whole, the western parts of the mines show black limestone, while the lower and eastern workings disclose metamorphosed white limestone.

The sections show that somewhat similar relations obtain for the Highland Boy limestone.

The section shows also that both limestones, in the western section at least, would soon encounter porphyry in their eroded upward extension. The strong dip of the contact toward the east would also seem to indicate that porphyry will be encountered in the deeper workings of the Utah Consolidated and the Utah Apex mines. Indeed, the Highland Boy limestone contains strong porphyry dikes on the 700-foot level and is almost wholly cut off by porphyry toward the east on number 13, 14, and 16 levels of the Utah Consolidated mine.

The elevations of the samples taken extend from 7,090 feet (number 1*b*) to 6,030 feet. Horizontally they extend over an interval of 2,400 feet.

The metamorphism consists in the enlargement of calcite grains and in the development in and between them of wollastonite, diopside, and fibrous tremolite; this growth often takes place between unaffected detrital quartz grains. Coarser aggregates appear in places with andradite and epidote, also pyrite and chalcopyrite. A little specularite is widely distributed. Apparently silicates and sulphides here crystallized in closely following stages. There are few, if any, pure crystalline limestones. Even specimens which so appeared contained in the clear calcite grains particles and prisms of garnet and tremolite. The amount of silicates varies considerably. Such metamorphosed limestones are shown in photograph in Boutwell's report[6] (plates 29, 30, and 34). Veinlets of later calcite often traverse the metamorphosed rocks. The metamorphism extends from a few hundred feet up to perhaps 2,000 feet from the porphyry contacts. The metamorphism invaded the limestone as an irresistible wave, leaving no unaltered sections and stopping short usually with an abrupt contact toward the black limestone, sometimes so sharp that the contact could be covered in one specimen. In other cases it spreads over some distance and for 50 or 100 feet the black limestone is spotted with white blotches and rings.

FIGURE 1.—*North-south Section 100 Feet West of Utah Apex Shaft, Bingham, Utah.*
In this section the Highland Boy limestone is altered (white) throughout. The Yampa limestone is unaltered (black) in the lower part only.

[6] J. M. Boutwell: Prof. Paper 38, U. S. Geol. Survey, 1905.

There is no graphite or other forms of carbon in the metamorphosed part. The carbon has been eliminated as some volatile compound.

Alteration by later solutions has affected the metamorphosed limestone to some degree, which finds expression in a slight hydration, apparent in the analyses. There is a little kaolin, perhaps also leverrierite, and a large amount of material with an index of refraction lower than Canada balsam. Some of this has a low birefringence and may be a zeolite; other parts are evidently related to serpentine and show higher birefringence. The secondary nature of this material is evident.

The iron occurs as pyrite and ferrous carbonate in the black limestone. In the metamorphosed rock there is usually much more pyrite and the iron in the silicates is in large part in the ferric state (as in andradite and epidote) and to less extent in ferrous state in the metasilicates. This naturally suggests that the abundant carbon dioxide may have exercised an oxidizing action on the emanations and the fact is in line with many other observations on contact zones. There is also a little specularite in the white limestone, but, as far as observed, no magnetite. In the following calculations the iron has been calculated as a metasilicate, the result, therefore, being the norm, rather than the mode, but there is no way of estimating the amount entering into the various iron silicates.

TABLE I.—*Analyses of unaltered and metamorphosed Limestone from Bingham, Utah*

(L. F. Hamilton, Analyst)

	1*b*	2*b*	3*w*	4*w*	5*w*	6*w*	7*b*	8*b*	9*w*	10*w*	11*b*	12*w*
Silica ..... SiO_2	28.47	29.11	36.66	49.27	35.20	33.33	29.34	27.28	24.22	28.11	78.80	83.44
Iron di-sulphide..... FeS_2	0.84	0.82	1.87	3.68	2.85	6.07	2.08	3.13	6.67	1.95	1.01	5.58
Iron oxide ..... FeO	1.33	1.03	4.20	2.20	3.96	1.32	0.86	0.05	0.77	1.30	3.09	3.62
Aluminum oxide ..... Al_2O_3	1.93	2.52	2.69	3.62	1.06	1.34	0.23	0.66	3.10	0.73	1.58	0.84
Calcium ..... CaO	36.02	35.92	34.14	24.17	41.35	31.06	37.02	35.59	33.25	42.48	4.06	0.97
Magnesium oxide ..... MgO	0.69	0.65	2.86	2.64	2.88	2.03	1.77	1.45	5.60	1.71	2.53	0.61
Sodium oxide ..... Na_2O	0.29	0.33	0.33	0.45	0.46	0.69	0.53	0.33	0.83	0.89	0.41	0.53
Potassium oxide..... K_2O	0.38	0.31	0.28	0.84	0.30	0.51	0.35	1.05	0.44	0.44	0.55	0.71
Carbon dioxide..... CO_2	28.80	28.10	17.35	13.10	10.92	22.15	27.12	28.65	23.31	21.59	6.36	0.55
Phosphorus pentoxide ..... P_2O_5	not det.	.....	.....	.....	0.24	0.28	0.12	0.24	0.21	0.17	0.08	0.07
Water 110° C..... H_2O	0.05	0.03	0.26	0.21	0.30	0.68	0.27	0.09	0.43	0.29	0.11	0.46
Water 800° C..... H_2O	1.10	0.61	0.52	0.62	1.08	0.86	0.79	1.52	0.86	0.67	1.57	2.32
Organic matter C	0.59	0.51	none	none	none	none	not. det.	.....	none	none	not. det.	.....
	100.49	99.94	101.16	100.80	100.60	100.32	100.48	100.04	99.69	100.33	100.15	99.70
Specific gravity (powder).....	2.64	2.62	2.63	2.69	3.05	2.61	2.62	2.57	2.81	3.03	2.58	2.67

THE ANALYSES

1*b*. Yampa black limestone, number 5 level, Utah Consolidated mine, west end. Elevation, 7,090 feet. Composite of samples 539–588, or 500 feet horizontal distance across whole formation. Stratigraphic thickness, 200 feet. No quartzite beds included. Residue insoluble in HCl, 31.08 per cent. After extraction of calcite with acetic acid there is marked effervescence with 6N hydrochloric acid, solutions containing much iron and magnesium and very little calcium.

2*b*. Yampa black limestone, cross-cut 13th level, Utah Consolidated mine opposite 7–16 shaft. Elevation, 6,360 feet. Composite of samples 589–633, or 450 feet horizontal distance across whole formation. Stratigraphic thickness, 215 feet. Residue insoluble in HCl, 31.26 per cent.

3*c*. Yampa white limestone cross-cut in Y. E. tunnel, east part Utah Consolidated mine. Elevation, 6,900 feet. Composite of samples 265–312, or 486 feet across whole formation. Stratigraphic thickness, 200 feet. Residue insoluble in HCl, 46.50 per cent. After extraction with acetic acid solutions showed much calcium with very little iron and magnesium. Residue treated with 6N hydrochloric acid showed effervescence and solutions contained much iron and fairly large calcium and magnesium; 33 samples out of 48 show small fractions of 1 per cent copper; none show lead. Iron varies from 1 to 6.8 per cent, increasing toward base of formation at Yampa vein.

4*c*. Yampa white limestone, cross-cut in Craig tunnel, east end of Utah Consolidated mine. Elevation, 6,660 feet. Composite of samples 358–420, or 620 feet horizontal distance across whole formation. Stratigraphic thickness, 194 feet. This includes one thin bed of quartzite near top. Composite also by error includes five samples of basal quartzite and five samples of sandy limestone at top, therefore shows too high silica. Residue insoluble in HCl, 57.10 per cent. Thirteen samples show traces or fractions of one ounce of silver. Five out of 58 show trace to 1.57 per cent lead. Ten out of 58 show fractions of 1 per cent copper. Iron and sulphur increase toward top and bottom of formation.

5*c*. Yampa white limestone, 47th cross-cut, number 13 level, Utah Consolidated mine. Elevation, 6,360 feet. Composite of samples, 197–227, or 320 feet horizontal distance, equal to stratigraphic thickness of 150 feet. Top of formation not exposed. Limestone contains 6 veinlets of sulphides parallel to stratification. Residue insoluble in 6N HCl, 50.02 per cent. Extractions with 2N acetic acid, 28.88 per cent. Twenty-one out of 31 samples contain from traces to 0.94 ounces silver; none give assays for lead; four gave fractions of 1 per cent of copper.

6*c*. Yampa white limestone, Climax cross-cut, main tunnel level, Utah Apex mine. Elevation, 6,600 feet. Cross-cut through whole formation, including samples 55–111, or 570 feet; 55 to 81 in white, silicated limestone; 82–111 in black limestone. Analysis, therefore, shows a mixture of about 50 per cent black and 50 per cent white. See under discussion of analysis. Total thickness, about 200 feet. Extraction with 2N acetic acid, 52.63 per cent. Residue insoluble in HCl, 41.68 per cent. Copper to fractions of 1 per cent was contained in 31 samples, mainly near bottom, near Yampa lode, and near top of formation. Two samples out of 57 gave assays for lead.

7*b*. Highland Boy black limestone, cross-cut on number 7 level, Utah Consolidated mine. Upper half of Highland Boy limestone. Elevation, 6,900 feet.

Composite of samples 150–189, or 400 feet horizontal distance obliquely across formation. Contains two 30-foot beds of sandy limestone. Stratigraphic thickness, about 100 feet. Residue insoluble in 6N, HCl, 34.77 per cent. Extraction with 2N acetic acid, 61.50 per cent. None of the samples gave commercial assays for lead or copper.

8*b*. Highland Boy black limestone, cross-cut in west part Utah Consolidated mine, number 13 level. Elevation, 6,360 feet. Composite sample of lower half of Highland Boy limestone. Ignited residue insoluble in 6N hydrochloric acid, 30.01 per cent. Extraction with 2N acetic acid, 67.70 per cent. No assays made.

9*w*. Highland Boy white limestone, number 7 tunnel, Utah Consolidated mine, obliquely across lower half of Highland Boy limestone. Elevation, 6,900 feet. Horizontal distance, 350 feet. Stratigraphic thickness, about 135 feet. Contains two small mineralized streaks and three narrow porphyry dikes of maximum width of 8 feet. Residue insoluble in 6N hydrochloric acid, 35.22 per cent. Extraction with 2N acetic acid, 54.15 per cent. Seven samples near porphyry dikes gave maximum assay of 2.8 per cent copper. No samples gave assays of lead.

10*w*. Highland Boy white limestone, number 16 level, Utah Consolidated mine. Elevation, 6,030 feet. Composite of samples 326–355, excluding samples 338 and 339, which were porphyry dikes. Horizontal distance of 280 feet. Thickness of about 200 feet. Residue insoluble in 6N hydrochloric acid, 35.63 per cent. Extraction with 2N acetic acid, 52.50 per cent. None of samples gave assays for copper or lead.

11*b*. Black sub-Yampa quartzite, number 13 level, Utah Consolidated mine, cross-cut to 7–16 incline shaft. Elevation, 6,030 feet. Upper half of a bed of quartzite between Yampa and Highland Boy limestones. Stratigraphic thickness, about 100 feet. Ignited residue after extraction with 6N hydrochloric acid, 83.71 per cent. Extraction with cold 2N acetic acid, 8.20 per cent. No assay.

12*w*. White sub-Yampa quartzite, cross-cut between Yampa and Highland Boy limestones, number 14 level, Utah Consolidated mine. Elevation, 6,250 feet. Composite of samples 242–263, excluding 245, which is a porphyry dike; in all, 220 feet horizontal distance. Stratigraphic thickness, 100 feet. Samples from lower part of quartzite bed not included, as it contains two small limestone beds. Residue insoluble in 2N hydrochloric acid, 93.44 per cent. Extraction with 2N acetic acid, 1.68 per cent. Of 22 samples 18 contained silver in traces or fractions up to 0.14 ounce. All samples contained copper up to 0.4 per cent. Iron is present from 3 to 10 per cent; sulphur from 1 to 6 per cent, one sample showing 9.17 per cent.

NOTE.—In all analyses the sulphur has been combined with Fe to FeS_2, there being no evidence of other sulphides or sulphates. For convenience the unaltered rocks are indicated by the letter *b*, the metamorphosed samples by *w*, thus 1*b* or 3*w*.

DISCUSSION OF THE BLACK YAMPA LIMESTONE

It is evident that number 1 and number 2 of the original analyses, though taken far apart, are almost identical in composition. The average

of the two analyses has, therefore, been accepted and is represented as number 13, recalculated to 100. Thin-sections show a very dark and fine-grained limestone, with numerous small rounded or subangular clastic fragments of quartz, orthoclase, and microcline. Organic remains are abundant, many of which consist of siliceous spiculæ of sponges. The silica is, therefore, present as quartz, as opal, or chalcedony, and as feldspathic silicates. Special tests show the presence of iron carbonate.

The determination of specific gravity of the powder proved difficult on account of floating organic substance. Five determinations averaged 2.61. Determination of specific gravity of fragments of the black limestone gave results varying from 2.67 to 2.72, the average being 2.71. The porosity of the unaltered limestones determined by A. N. Winchell[7] averaged about 4 per cent.

The calculation of non-porous rock gives 2.685, which has been accepted as basis for calculation of gains and losses.

TABLE II.—*Calculation of Analyses of black Yampa Limestone*

	Number 13	Mol. W.	Composition	
SiO_2	28.90	.480	$CaCO_3$	64.30
FeS_2	.83	.007	$MgCO_3$	1.42
FeO	1.49	.021	$FeCO_3$	2.44
Al_2O_3	1.23	.012	FeS	.83
CaO	36.21	.644	Albite and orthoclase	4.86
MgO	.67	.017	Kaolin	.77
Na_2O	.31	.005	SiO_2	25.20
K_2O	.35	.005	C	.55
CO_2	28.56	.649		100.37
P_2O_5	....	....		
H_2O—	.04	.050		
H_2O+	.86			
C	.55	.046		
	100.00			

No. 13.—Average of number 1 and number 2.

Mol. W.—Molecular weights.

Composition.—Calculated mineralogical composition. There is 0.79 per cent water, which is not accounted for, and there is a deficiency of 1.98 per cent CO_2. The excess of water may be due to microscopic chlorite and sericite, which have not been calculated.

From the composition calculated for number 13, the specific gravity of the mixture may be determined. The figures adopted for the successive minerals are as follows: 2.71, 3, 3.8, 5, 2.6, 2.6, 2.64, and 1.

[7] Op. cit., p. 12.

Thus we obtain, by dividing the weights by the specific gravities, the following volumes:

$CaCO_3$	23.73
$MgCO_3$	.47
$FeCO_3$	.64
FeS_2	.17
Feldspars	1.86
SiO_2	9.55
Kaolin	.30
Organic	.55
	37.27

Now, as 37.27 is the volume occupied by 100 grams, the specific gravity is 2.683. In this the porosity has not been considered. Assuming 1 cubic centimeter pore space, or about 3 per cent, the bulk specific gravity of the limestone calculates to 2.61.

Discussion of altered (white) Yampa Limestone

In discussing the four analyses of metamorphosed Yampa limestone (3, 4, 5, and 6) it should first be observed that, though in general they are entirely similar, number 4 contains much more SiO_2 and also more Al_2O_3 than any of the others; this is because several samples of basal quartzite were inadvertently introduced; also about five samples of the top rock, which is here a very siliceous limestone. An attempt has been made to correct this analysis (page 520). The others show, compared to the unaltered limestones number 1 and number 2, or the average of these, number 13, an increase of 5 to 8 per cent SiO_2, a distinct increase of FeS_2 and MgO, a strong but variable decrease in CO_2, and a removal of carbon. Alkalies and water are not greatly changed. Calcium oxide is lowered in two and increased in two of the analyses compared with the average of the unaltered rock.

Thin-sections show a coarsely crystalline limestone, with variable amounts of wollastonite and tremolite, generally in fine-grained, felted aggregates and embedded in calcite. Epidote and a garnet (andradite or grossularite) appear in spots, but are not abundant. The minutely distributed pyrite of the unaltered rock here appears in coarser grains or aggregates, and it is more abundant. Detrital grains of quartz and more rarely feldspar are almost always present. Some of the specimens are traversed by veins of coarsely crystalline calcite. No fossil remains nor carbonaceous matter are seen.

The specific gravity of the powder gave, as indicated, on the principal

table 2.61, 2.62, 2.63, and 3.05, the last-named figure being obtained from the rock with least carbon dioxide.

TABLE III.—*Calculation of 3w, Yampa white Limestone*

	3w	Mol. W.	Mineralogical composition		Specific gravity	Volumes in 100 grams
SiO_2	36.66	0.611	Calcite	39.40	2.71	14.53
FeS_2	1.87	.....	Pyrite	1.87	5.00	.37
FeO	4.20	0.058	Feldspar	4.19	2.60	1.61
Al_2O_3	2.69	0.026	Kaolin	4.64	2.60	1.79
CaO	34.14	0.610	$CaSiO_3$	25.06	2.90	8.64
MgO	2.86	0.071	$MgSiO_3$	7.10	3.20	2.22
Na_2O	.33	0.005	$FeSiO_3$	7.66	3.70	2.07
K_2O	.28	0.003	SiO_2	10.92	2.64	4.13
CO_2	17.35	0.394				
H_2O-	.26	0.029		100.84	2.83	35.36
H_2O+	.52					
	101.16					

Assuming 4 per cent porosity, the volume of 100 grams would be 35.36 + 1.40 = 36.76, which corresponds to a specific gravity of 2.72.

The 4w analysis has been referred to above as including by error five samples of quartzite below the Yampa base, and therefore containing too much silica. In this section the uppermost part of the formation also contains some beds of siliceous limestone, which would tend to make the silica higher than normal. An attempt has been made to correct the analysis for the five quartzite samples, assuming a quartzite containing 90 per cent SiO_2. The recalculation leads to the following corrected percentages:

TABLE IV.—*Calculation of number 4w, Yampa white Limestone in Craig Tunnel*

	Number 16	Mol. W.	Mineralogical composition		Specific gravity	Volumes in 100 grams
SiO_2	46.79	.779	Calcite	30.70	2.71	11.32
FeS_2	3.79	....	Pyrite	3.79	5.00	.76
FeO	2.27	.032	Feldspars	9.00	2.60	3.46
Al_2O_3	3.73	.036	Kaolin	5.42	2.60	2.08
CaO	24.97	.446	Quartz	23.82	2.64	9.59
MgO	2.73	.068	$CaSiO_3$	16.12	2.90	5.56
Na_2O	.46	.007	$MgSiO_3$	6.80	3.20	2.13
K_2O	.87	.010	$FeSiO_3$	4.22	3.70	1.14
CO_2	13.53	.307				
H_2O-	.22	.035		99.87	2.78	35.94
H_2O+	.64					
	100.00					

Number 16.—Number 4w recalculated to 100 and corrected for excess silica.

This analysis calculates very satisfactorily, there being no excess or deficiencies.

TABLE V.—*Calculation of 5w, composite Sample across Yampa Limestone, white and altered.*

Number 5w		Mol. W.	Mineralogical composition	
SiO_2	35.20	.587	Calcite	23.70
FeS_2	2.85	....	Pyrite	2.85
Al_2O_3	1.06	.016	Feldspars	5.24
FeO	3.96	.055	Apatite	0.50
CaO	41.35	.738	Kaolin	1.57
MgO	2.88	.072	$CaSiO_3$	57.54
Na_2O	0.46	.007	$MgSiO_3$	1.90
V_2O	0.30	.003	MgO	2.12
CO_2	10.92	.237	FeO	3.96
P_2O_5	0.24	.0015	Quartz	none
H_2O—	0.30	.059		
H_2O+	1.08			99.38
	100.60			

The analysis shows a slight excess of water and a decided deficiency in SiO_2. If all of the CO_2 is used for calcite, there is not enough silica to combine with remaining CaO, MgO, and FeO. Part of MgO and all of FeO remains unsatisfied, leading to the assumption of the presence of spinel, magnetite, or specularite in the rock. The extract with acetic acid—that is, calcite—is given as 28.88. The analysis looks of doubtful accuracy.

Calculation of specific gravity has not been attempted in view of these discrepancies. The figure is probably not far from 2.90.

This sample comprises about 40 per cent of white altered rock and 60 per cent of black unaltered limestone. Through an error a composite sample was made of both, the analysis thus showing an average of the composition of black and white rock. For direct comparison this analysis should not be used, but it is pointed out that the composition is in close correspondence to the requirements of such a mixture.

TABLE VI.—*Calculation of number 6w, Yampa white Limestone*

Number 6w		Mol. W.	Mineralogical composition		Specific gravity	Volumes in 100 grams
SiO_2	33.33	.555	Calcite	50.30	2.71	18.56
FeS_2	6.07	....	Pyrite	6.07	5.00	1.20
FeO	1.32	.018	Feldspar	8.28	2.60	3.19
Al_2O_3	1.34	.013	Apatite	0.67	3.20	0.21
CaO	31.06	.555	$CaSiO_3$	5.34	2.90	1.53
MgO	2.03	.050	$MgSiO_3$	5.00	3.22	1.55
Na_2O	0.69	.011	$FeSiO_3$	2.38	3.70	0.64
K_2O	0.51	.005				
CO_2	22.15	.503			2.88	
P_2O_5	0.28	.002	Quartz	20.70		7.80
H_2O—	0.68	.048				
H_2O+	0.86					34.68
	100.32		Water	0.86		
				99.60		

This analysis is calculated without trouble. There is scarcely any excess of alumina. The water remains uncertain, probably entering into some sericite, serpentine, and chlorite.

Considering 4 per cent of porosity, we obtain an additional volume of 1.39 cubic centimeters, or 36.07, giving bulk specific gravity 2.77.

TABLE VII.—*Summary of Mineralogical Composition of Yampa Limestone, black and white*

	13	6w	16	3w	5w
Calcite	64.30	50.30	30.70	39.40	23.70
Magnesite	1.42	.....	.....	.....	.....
Siderite	2.44	.....	.....	.....	.....
Pyrite	.83	6.07	3.79	1.87	2.85
Apatite	.....	0.67	.....	.....	0.50
Feldspars	4.86	8.28	9.00	4.19	5.24
Kaolin	0.77	.....	5.42	4.64	1.57
Carbon	0.55	.....	.....	.....	.....
Quartz	25.20	20.70	23.82	10.92	none
$CaSiO_3$	.....	5.34	16.12	25.06	57.54
$MgSiO_3$	.....	5.00	6.80	7.10	1.90
$FeSiO_3$	.....	2.38	4.22	7.66	[1]6.08
	100.37	98.74	99.87	100.84	99.38
Specific gravity	2.685	2.88	2.78	2.83	2.90

13.—Average of 1-2 black limestone.

6w.—Yampa white limestone. Sample is a mixture of 60 per cent limestone and 40 per cent white metamorphosed rock.

[1] 6.08 = MgO. 2.12 + FeO 3.96 unassigned.

16.—Yampa white limestone. Recalculated and corrected for excess silica from number 4*w*.

3*w*.—Yampa white limestone.

5*w*.—Yampa white limestone.

TABLE VIII.—*Gains and Losses in Grams per 100 cubic centimeters in Yampa Limestone*

(On basis of equal volumes)

	13*b*	6*w*	5*w*	3*w*	16	6–13	5–13	3–13	16–13
SiO_2 ...	77.60	95.99	102.08	103.75	130.08	+18.39	+24.48	+26.15	+52.48
FeS_2 ...	3.23	17.48	8.27	5.29	10.54	+15.25	+ 6.04	+ 2.06	+ 8.31
FeO ...	4.00	3.80	11.48	11.88	6.31	+ 0.20	+ 7.48	+ 7.88	+ 2.31
Al_2O_3 ..	3.30	3.86	3.07	7.61	10.37	+ 0.56	+ 0.23	+ 4.31	+ 7.07
CaO ...	97.22	89.45	119.92	96.62	69.40	— 7.77	+22.70	— 0.60	—27.80
MgO ...	1.80	5.85	8.35	8.09	7.59	+ 4.05	+ 6.55	+ 6.29	+ 5.79
Na_2O ..	0.83	1.99	1.33	0.93	1.28	+ 1.16	+ 0.50	+ 0.10	+ 0.45
K_2O ...	0.94	1.47	0.87	0.79	2.42	+ 0.53	— 0.07	— 0.15	+ 1.42
CO_2 ...	76.68	63.79	31.67	49.10	37.61	—12.92	—45.01	—27.58	—39.07
P_2O_5 ...	not det.	0.81	0.70	not det.	not. det.	.....	.....	.....	.....
H_2O+..	2.30	2.48	3.13	1.40	1.78	+ 0.18	+ 0.83	— 0.90	— 0.52
C	1.48	none	none	none	none	— 1.48	— 1.48	— 1.48	— 1.48
	269.38	286.97	290.87	285.46	277.38	+18.15	+21.79	+16.08	+ 8.96
Sp. G... (calculated)	2.685	2.88	2.90	2.83	2.78				

13*b*.—Black unaltered Yampa limestone. Grams per 100 cubic centimeters.

6*w*.—White metamorphosed Yampa limestone. Sample is a mixture of 40 per cent black and 40 per cent white limestone and does not represent the composition of normal white limestone.

5*w*.—White metamorphosed Yampa limestone.

3*w*.—White metamorphosed Yampa limestone.

16.—White metamorphosed Yampa limestone.

6–13.—Total gain, 40.32; total loss, 22.17; balance gain, +18.15.

5–13.—Total gain, 68.58; total loss, 46.79; balance gain, +21.79.

3–13.—Total gain, 46.79; total loss, 30.71; balance gain, +16.08.

16–13.—Total gain, 77.83; total loss, 68.87; balance gain, +8.96.

SUMMARY DISCUSSION OF THE METAMORPHISM OF THE YAMPA LIMESTONE

The first thing that stands out is the striking similarity, almost identity, of the two analyses of unaltered limestones. These composite samples are 750 feet apart vertically and 700 feet horizontally. At both places the samples extend across the whole formation. The limestones contain throughout a little finely divided FeS_2, and chemical tests indicate that a small amount of the carbonates of iron and magnesia are also

present. They contain 25 per cent quartz (with chalcedony), about 5 per cent feldspars in detrital grains, carbon, or hydrocarbons, 64 per cent calcite, and probably a little kaolin. They are, therefore, siliceous limestones.

Considering now the mineralogical composition (Table VII) of the four metamorphosed sections, it is apparent that they comprise a graduated series in which the decrease of calcite is more or less strongly marked. It is difficult to connect this with the distance from the intrusive, for, though probably the silicates are more abundant near the monzonite porphyry, there is no definite increase of silication up to the contact. On the whole, the contact is very sharp and the metamorphism appears to be about as complete close to the contact as away from it. In other words, the reaction stopped short at a certain point, and up to this point the limestone was apparently fully saturated with the emanations from the magma. Garnet and epidote are, however, more common in the vicinity of the intrusives. The contacts with the monzonite are not well exposed. The emanations appear to have come in part from the lower part of Carr Fork and in part from the long now eroded contact at which the limestone continued up on the dip bordered against the monzonite now shown on the south side of the Carr Fork.

The free quartz shows a gradual decrease from 25 per cent to 11 per cent and to nothing (in 5*w*). Probably analysis 4, recalculated as number 16, still contains too much silica on account of admixed very siliceous beds in the uppermost part.

Magnesite and siderite do not appear to be present in the altered rocks and indeed, with SiO_2 as the stronger acid, would not be expected to be stable. Pyrite shows a consistent and strong increase from 0.83 in the fresh rock to 6.07 per cent in number 6*w*.

Regarding the feldspars, some doubt may be admitted. Analyses 6*w* and 16 show a decided increase, but whether this is accidental or owing to introduced Al_2O_3 in some metamorphic mineral is not certain. On the face of it, it looks as though some alumina may have been added. Take, for instance, 5*w*, which shows that all of the quartz has been used up, for silicates still calculate to 5.24 per cent feldspars, or more than in the original rock. It is not probable that the detrital feldspars should have escaped some recrystallization any more than the quartz, and it seems likely that in this analysis the alkali feldspars have at least been recrystallized to some other mineral.

Kaolin is generally present in quantities larger than in the unaltered rock, and there is usually some combined water left after the calculation, which points to the probable existence of products like chlorite, serpentine, or asbestiform minerals impossible to identify.

The quartz has been largely used up for the new silicate minerals, but besides there has also taken place, as shown later, a decided introduction of new silica.

The new silicates are mainly wollastonite and tremolite and have been so calculated. The ferrous oxide has also been calculated as a metasilicate $FeSiO_3$. In places there is certainly epidote, garnet, and other silicates, but they are subordinate and could not well be accounted for in the calculation.

The Ca, Mg. Fe metasilicates range from 27.14 per cent in number 16 to 39.82 per cent in $3w$ and to a maximum of 65.52 per cent in $5w$.

The calculated specific gravities have been adopted for subsequent calculations as more reliable than those determined by pycnometer in the powdered samples. It is probably very difficult to secure an exact determination in case of such a finely powdered material which forms suspensions and slimes.

Summary Discussion of Gains and Losses on Basis of equal Volumes in the Yampa Limestone

In Table VIII the several analyses have been multiplied by the calculated specific gravity to obtain grams per 100 cubic centimeters under the assumption that no expansion or contraction has taken place during metamorphism. It should be recalled that number $6w$ is a mixture of black and white limestone. The table is arranged by increasing silica, which shows an addition of from 24.48 to 52.48 grams per 100 cubic centimeters.

The addition of pyrite is marked and unmistakable. The actual addition of pyrite in number $6w$ is 15.25 ounces per 100 cubic centimeters, or 150 kilograms per cubic meter. The addition of FeO is likewise perfectly evident. An introduction of alumina is very probable, but perhaps not conclusively proved.

Lime behaves erratically. Normally one would expect a loss, and this has taken place in three of the metamorphosed rocks, but in the fourth an addition of 22.70 grams per 100 cubic centimeters is indicated equivalent to about 20 per cent.

Magnesia is uniformly and consistently increased, the maximum amounts introduced being 6.55 grams per 100 cubic centimeters.

Soda has increased in all cases, but in regard to potassium the results are not at all consistent.

Carbon dioxide is uniformly decreased, as would indeed be expected, to a minimum of half of the original amount.

There is probably little or no change in phosphoric acid. No definite conclusion can be drawn as to the combined water. Normally it would decrease during metamorphism, but the altered rocks have been exposed to hydration, with the result of formation of hydrated silicates.

Carbon or the hydrocarbons are eliminated.

The final result is a gain of substance amounting to from 9 to 22 grams per 100 cubic centimeters. The total gains vary from 47 to 78 grams per 100 cubic centimeters; the total losses from 22 to 69 grams per 100 cubic centimeters.

Losses plus gains range from 27 per cent to 52 per cent of the original mass. This percentage has moved in or out of the rock. It is larger than the corresponding figures for the Highland Boy limestone.

Discussion of the black Highland Boy Limestone

The two analyses, 7*b* and 8*b*, of the unaltered Highland Boy limestone are so closely alike that the average of the two can well be taken. This is given below under number 14. In silica, lime, and carbon dioxide the average is almost identical with number 13, representing the Yampa limestone. The only differences are somewhat higher pyrite and magnesia and lower ferrous oxide. Microscopically the two limestones are practically identical. The specific gravities given in the main table are probably too low, and for the same reason given above in the discussion of the Yampa limestone the figure 2.685 has been adopted.

Table IX.—*Calculation of Analysis of black Highland Boy Limestone*

Number 14		Mol. W.	Mineralogical composition	
SiO_2	28.31	.471	$CaCO_3$	64.18
FeS_2	2.60	....	$(MgFe)\ CO_3$	1.64
FeO	0.45	.006	FeS_2	2.60
Al_2O_3	0.45	.004	Orthoclase	8.80
CaO	36.30	.648	Albite	
MgO	1.61	.040	Sericite	
Na_2O	0.43	.006	Apatite	0.41
K_2O	0.70	.007	Quartz	22.51
CO_2	27.88	.634	Organic carbon (assumed)	0.55
P_2O_5	0.18	.001		
H_2O-	0.18	.075		
H_2O+	1.16			
C	not det.			
	100.25			100.69

The volumes of the items of mineralogical composition obtained as before by dividing by the same specific gravities would yield:

$CaCO_3$	23.68
$Mg(Fe)SiO_3$	0.55
FeS_2	0.52
Feldspars and sericite	3.40
Apatite	0.13
SiO_2	8.52
Organic (assumed)	0.55
	37.35

This corresponds to a specific gravity of 2.685. Adding 1 cubic centimeter of assumed pore space, about 2 per cent, to the volume gives a total volume of 38.35, which corresponds to a specific gravity of 2.61, practically the same figures as were obtained for the Yampa black limestone.

The analysis is not quite satisfactory. It shows a small deficiency of CO_2 and Al_2O_3 and an excess of water. In part the H_2O may belong to finely divided sericite or other hydrous silicates.

Discussion of the altered (white) Highland Boy Limestone

The analysis 9*w* of an average across the lower 135 feet of the Highland Boy limestone includes three narrow porphyry dikes. Possibly the latter may have raised the silica and alumina slightly. The rock is white crystalline with some pyrite, but nowhere shows complete silication. Calcite was extracted with 2N acetic acid and amounted to 54.15 per cent.

Table X.—*Calculation of 9w, composite Sample of lower Highland Boy altered, white Limestone adjoining 7b*

	9w	Mol. W.
SiO_2	24.22	.404
FeS_2	6.67	....
FeO	0.77	.010
Al_2O_3	3.10	.030
CaO	33.25	.593
MgO	5.60	.140
Na_2O	0.83	.014
K_2O	0.44	.004
CO_2	23.31	.530
P_2O_5	0.21	.001
H_2O-	0.43	.047
H_2O+	0.86	
Organic	none	
	99.69	

Under the assumption that little or no siderite or magnesite is present, the mineralogical composition would be as follows:

		Specific gravity	Volumes in 100 grams
Calcite	53.00	2.71	19.53
Pyrite	6.67	5.00	1.33
Apatite	0.48	3.20	0.15
Feldspars	10.00	2.60	3.85
Kaolin	3.10	2.60	1.19
$CaSiO_3$	6.96	2.90	2.39
$MgSiO_3$	14.00	3.20	4.38
$FeSiO_3$	1.32	3.70	0.36
Quartz	3.72	2.64	1.41
	99.25	2.89	34.59

Assuming that the rock has a porosity of 4 per cent, we obtain specific gravity 2.69.

The calculation leaves a small excess of H_2O+, which it is assumed enters into hydrated metasilicates.

TABLE XI.—*Calculation of 10w, composite Sample of upper Part Highland Boy altered white Limestone*

10*w*		Mol. W.	Mineralogical composition		Specific gravity	Volumes in 100 grams
SiO_2	28.11	.468	Calcite	49.10	2.71	18.12
FeS_2	1.95	....	Pyrite	1.95	5.00	0.39
FeO	1.30	.018	Apatite	0.34	3.20	0.11
Al_2O_3	0.73	.007	Feldspars	10.00	2.60	3.85
CaO	42.48	.759	$CaSiO_3$	30.74	2.90	10.60
MgO	1.71	.043	$MgSiO_3$	4.30	3.20	1.34
Na_2O	0.89	.015	$FeSiO_3$	2.38	3.70	0.64
K_2O	0.44	.004	Quartz	2.28	2.64	0.85
CO_2	21.59	.491				
P_2O_5	0.17	.001		101.09	2.80	35.90
H_2O-	0.29	.054				
H_2O+	0.67					
	100.33					

The excess in the addition is due to deficiency of alumina for feldspars in the analysis.

Assuming a porosity of 4 per cent, the total volume would be $35.90 + 1.40 = 37.30$ and the bulk specific gravity would be 2.68.

TABLE XII.—*Summary of mineralogical Composition of Highland Boy Limestone, black and white*

	14	9*w*	10*w*
Calcite	64.18	53.00	49.10
Magnesite } Siderite }	1.64	.....	.....
Pyrite	2.60	6.67	1.95
Apatite	0.41	0.48	0.34
Feldspars	8.80	10.00	10.00
Kaolin	.....	3.10	.....
Carbon	0.55 *	.....	.....
Quartz	22.51	3.72	2.28
$CaSiO_3$	.....	6.96	30.74
$MgSiO_3$	.....	14.00	4.30
$FeSiO_3$	.....	1.32	2.38
	100.69	99.25	101.09
Specific gravity	2.685	2.89	2.80

14.—Average of 7*b* and 8*b* Highland Boy black limestone.
9*w*.—Altered white Highland Boy limestone.
10*w*.—Altered white Highland Boy limestone.

TABLE XIII.—*Gains and Losses in Grams per 100 cubic centimeters in Highland Boy Limestone*

(On basis of equal volumes)

	14	9*w*	10*w*	9–14	10–14
SiO_2	76.01	69.99	78.71	— 6.02	+ 2.70
FeS_2	6.98	19.28	5.46	+12.30	— 1.52
FeO	1.21	2.23	3.64	+ 1.01	+ 2.43
Al_2O_3	1.21	8.96	2.04	+ 7.75	+ 0.83
CaO	97.46	96.09	118.94	— 1.37	+21.48
MgO	4.32	16.18	4.79	+11.86	+ 0.47
Na_2O	1.16	2.40	2.49	+ 1.24	+ 1.33
K_2O	1.88	1.27	1.23	— 0.61	— 0.65
CO_2	74.86	67.36	60.45	— 7.50	—14.41
P_2O_5	0.48	0.61	0.48	+ 0.13	.....
H_2O+	3.12	2.48	1.88	— 0.64	— 1.24
C	not det.	none	none	.....	.....
	268.69	286.85	280.11	+18.15	+11.42

Number 14.—Average of 7*b* and 8*b*. Unaltered black limestone × 2.685.

9*w*.—Altered Highland Boy limestone × 2.89. Total gains, 34.39; losses, 16.14; balance, +18.15.

10*w*.—Altered Highland Boy limestone × 2.80. Total gains, 29.24; losses, 17.82; balance, +11.42.

* Assumed.

Summary Discussion of the Metamorphism of the Highland Boy Limestone

There are two analyses of the average composition of the unaltered Highland Boy limestone. They agree almost exactly, although number 7*b* is only from the upper half of the limestone and number 8*b* is from the lower half of the formation. The average in number 14 is extremely close to the average of the Yampa limestone, and the composition consists of calcite, with a small amount of siderite and magnesite, but with a somewhat higher percentage of pyrite than in the Yampa limestone. The feldspars are also notably higher than in the Yampa.

Considering now the mineralogical composition of the metamorphosed sections, there are only two analyses available. The first, number 9*w*, represents the altered lower part of the formation adjacent to number 7*b*, which includes the upper half of black limestone. The second, number 10*w*, is from the deepest level (number 16) of the Utah Consolidated mine, about 900 feet below number 9.

Comparing the mineralogical composition of the fresh and altered rocks (Table XII), it appears that calcite decreases from 64.18 per cent to a minimum of 49.10 per cent. Pyrite increases strongly in 9*w*, but is actually less in 10*w*, which is heavily silicated. Magnesite and siderite are believed to be absent in the metamorphosed rocks. The calculation shows apparently that the feldspars remain about the same, while the quartz may be almost wholly gone. This is unlikely and suggests that new alkaline aluminum minerals not readily visible may have been formed. Quartz is almost wholly recrystallized to silicates in 9*w* and 10*w*. The metasilicates in the last two analyses are 22.28 and 37.42 per cent respectively. In 9*w* the unusual condition obtains that the magnesium silicate is in excess of the calcium silicate.

Summary Discussion of Gains and Losses on Basis of equal Volumes in the Highland Boy Limestone

In Table XIII the several analyses have been multiplied by the calculated specific gravities to obtain grams per 100 cubic centimeters. In regard to silica, there has been comparatively little change, certainly no consistent increases as in the Yampa limestone. One analysis shows a slight loss, the other a slight gain. Ferrous oxide is decidedly increased. In the case of 10*w*, where a decrease of pyrite has taken place, the total iron is nevertheless increased. There seems to be a decided gain of alumina, though in 9*w* three small included porphyry dikes doubtless contribute to the unusually large Al_2O_3. Lime in 9*w* remains about the same, while a very strong addition has occurred in 10*w*.

Magnesia is increased, soda likewise. Potassium appears slightly reduced, but no definite conclusion can be drawn from the figures. Carbon dioxide is lost to the extent of 7.50 and 14.41 grams per 100 cubic centimeters out of 74.86 in the black limestone.

Combined water seems slightly reduced, and, of course, carbon or hydrocarbons are removed.

As a general result, there has been a notable loss of carbon dioxide, a slight gain or loss in silica, a decided addition of ferrous oxide, also of magnesia, alumina, and soda. Lime has remained stationary in one analysis and has been greatly increased in the other.

The final result is a gain of substance amounting to 11.42 and 18.15 grams per 100 cubic centimeters respectively. The total gains are 29.24 and 34.29 respectively; the total losses, 16.14 and 17.82. Losses plus gains amount to about 17 per cent of the original mass. This percentage of matter has moved in or out of the rock, disregarding movements of matter that has remained in the limestone.

Porosity

The discussion so far has disregarded porosity for the reason that it can not be accurately determined for the whole thickness of rocks. Reference has been made above to the determinations by Prof. A. N. Winchell. He obtained for unsilicated rocks with 25 per cent quartz the average of 1.8 per cent, for partly silicated rocks an average of 5.9, which is probably too high, as it includes one determination out of ten which showed an apparently abnormal porosity of 18 per cent. In completely silicated rocks the porosity was only 3.3 per cent in average. These data agree in general with my observations.

If the rocks have a porosity, the effect will be to reduce the calculated specific gravity. Assuming, for instance, that the porosity of the black limestone (number 13 and number 14) is 3 per cent, this will increase the calculated volumes 37.27 by 1 cubic centimeter, making the total volume 38.27, and also reduce the calculated specific gravity 2.685 by 0.7 or to 2.615. This again will reduce the grams per 100 cubic centimeters (Tables VIII and XIII) by about 2.5 per cent.

In a similar way, in analysis 3*w*, assuming a porosity of 6 per cent will reduce the calculated specific gravity from 2.83 to 2.68, a reduction of 0.15. This again, in Table VIII, will reduce the grams per 100 cubic centimeters by about 5 per cent. Consequently the gains will be decreased and losses will be increased by about 2.5 per cent, which again will tend to reduce the balance gains. The general results, as outlined

above, will not be materially affected by porosity even if averaging 6 per cent in the altered rock.

Comparison of Metamorphism of Yampa and Highland Boy Limestone

Though the compositions of the Yampa and the Highland Boy limestones are practically identical, the metamorphism of the two has proceeded on different lines. In the Highland Boy formation the quartz has been almost completely used up for the development of silicates, whereas in the Yampa limestone much SiO_2 has been added, and the silicates have mainly been formed from the silica contributed by the magma. In the case of number *5w* in the Yampa limestone, about 65 per cent of silicates have formed, using up all of the detrital quartz and a magmatic gain of 24 grams per 100 cubic centimeters in addition. As silicates will be more easily formed from the fluid or gaseous silica than from detrital grains, it would seem to follow that the Highland Boy limestone had been exposed to higher temperatures than the Yampa. This is probably true, for it includes large masses and dikes of porphyry.

Consideration of Errors

It is well to realize that the figures tabulated above are mere approximations, say within 5 to 20 per cent of the actual figures. The sources of errors are many: in the sampling, in the preparation and mixing of the samples, in the chemical analyses, and in the determinations of the specific gravity. Even considering all this it is certain that the results outlined above will stand, generally speaking, and that the actuality of magmatic additions of silica, ferrous and ferric iron oxide, magnesia, and iron sulphide are proved.

Change of Volume

During the progress of the field examinations preparatory to the trial in the courts there was general agreement between the geologists that no measurable decrease of volume had taken place during the metamorphism. This was specially well established in the case of the Yampa limestone. In case of the composite samples *1b*, *2b*, *3w*, and *4w* of the Yampa limestone, where the thickness could be accurately measured, it was found to be respectively 200, 215, 200, and 194 feet. This conclusion has been confirmed by Prof. A. N. Winchell[9] as follows: "The numerous vertical

[9] Petrographic studies of limestone alterations at Bingham. Trans. Am. Inst. Min. and Met. Engs., New York meeting, February, 1924, pp. 6 and 7.

sections through the Highland Boy limestone and other formations, carefully worked out for the lawsuit, show that there has been no decrease of volume as a result of the change of the limestone to lime-silicate rock."

Microscopic evidence shows also, and again I agree with Professor Winchell "that the original quartz is not used (at least in all cases) in the formation of lime silicate, for in some thin-sections the calcite matrix has been converted completely into lime-silicate minerals with no encroachment on the rounded outlines of the detrital quartz grains."

The equation $CaCO_3 + SiO_2 = CaSiO_3 + CO_2$ would call for a reduction of volume of 31.48 per cent, provided the silica was a solid in the limestone. If the silica was introduced from the outside as a fluid, there would be an increase of volume of 10.81 per cent.[10] I hold, however, that during replacement there has been no change of volumes in general, the volume of replaced material equaling that introduced. As a matter of fact, if there has been no change of volume the above equation is incorrect, and the reaction involves a loss of CaO as well as of CO_2.[11] This finds expression in the fact that in the altered rocks lime as well as CO_2 is carried away. But in metamorphic action like that here described the movement of matter has been intense and variable. Two of the six analyses of altered rocks show a strong addition of CaO.

Alteration of sub-Yampa Quartzite

The last two analyses in the general table (11*b* and 12*w*) represent respectively unaltered black sandstone and altered white rock of the same kind. It has not been thought worth while to recalculate these. In general, the black sandstone consists of detrital quartz and feldspar grains and contains about 7.2 per cent calcite, 5.12 per cent magnesite, 1.28 per cent siderite, and 1.01 per cent pyrite, leaving about 2 per cent of FeO unaccounted for.

The alteration consists in an increase of silica, iron oxide and pyrite, and a very marked removal of carbonates. Only a small amount of calcium or magnesium silicates can be present. A considerable mineralization has, therefore, taken place with the introduction of sulphur and silica. Almost every sample showed silver and copper from traces to a fraction of one per cent.

[10] C. R. Van Hise: Metamorphism. Mon. 47, U. S. Geol. Survey, 1904, p. 239.

[11] W. Lindgren: The nature of replacement. Economic Geology, vol. 7, 1912, pp. 521-535; Volume changes in metamorphism. Jour. Geology, vol. 26, 1918, pp. 542-554.

Conclusion

The chemical investigations in this paper show that at Bingham, as a consequence of metamorphism, the siliceous limestones of the Yampa and the Highland Boy formations have gained silica, sulphur, iron magnesia, alumina, and soda, and that carbon dioxide and (generally) lime have been carried away. There has been a well defined gain of substance amounting to from 4 to 8 per cent. The additions range from 8 to 29 per cent and the losses from 4 to 20 per cent. The volume of the limestone has remained approximately constant.

While strong silication, and especially the development of garnet, seems favored by the proximity of the contact with the intrusive, silication in this case has proceeded right up to the sharp contact with unaltered rock. There are in these limestones no separate masses in which marmorization has been effected without silication.

On account of the great irregularity of the intrusions, it is difficult to say just how far from the contact the metamorphism has proceeded. Generally speaking, it extends from a few hundred feet to a maximum of two thousand feet from the igneous contact.

The metamorphism was accompanied by the introduction of pyrite and chalcopyrite, probably also other sulphides, but only to a moderate extent. They formed practically simultaneously with the silicates. The ore deposits of importance were formed at a distinctly later stage in part with the development of silicates, but continuing to form until the temperature had fallen far below the point of silication. The calcareous quartzite has likewise been metamorphosed, and apparently quartz has developed in it with pyrite and a small amount of calcium silicates.

In closing, the difference between dynamic and igneous metamorphism might well be emphasized. In recrystallization under pressure silication may likewise take place in siliceous limestone, but these changes are slow; the solutions percolate with minimum speed and the final result may take a million years. The recrystallized rock has little porosity. Plenty of time is available for the development of a solid non-porous rock. In igneous metamorphism, on the other hand, the recrystallizing agents or fluids rush out from the intrusive and pass through the limestone like water through a sponge. The reactions and interchanges take place rapidly; sometimes solutions run ahead of precipitation and porosity may develop. The whole process might well be completed in a few years. This expresses the difference between slow and fast work by the processes of nature.

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MINERALOGY AND PETROGRAPHY OF FOSSIL BONE*

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(Presented before the Society December 28, 1923)

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INTRODUCTION

It seems strange that natural history specimens as common and widely distributed as fossil bones have received practically no study by the mineralogist. Realizing that they are fossils, the mineralogist has evidently left them to the consideration of the paleontologist, but the paleontologist is concerned only with their form and has little if any interest in the material of which they are composed.

Very little is said in the literature as to the nature of fossil bones, but the belief on the part of many geologists is that they are silicified. This misapprehension is probably due to their superior hardness and specific

Dedicated to the memory of the late Samuel Wendell Williston.

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gravity over that of recent bones.[1] But as a matter of fact silicified bone is exceedingly rare. Of the fossil bones studied by the writer, which number roughly about 300, only three were found to be silicified. Instead of being silicified, fossil bones are phosphatized and consist almost exclusively of the mineral *collophane*, a hydrous calcium carbonate-phosphate, which is the chief constituent of phosphorite or so-called phosphate rock. This was discovered by the writer[2] and announced by him in 1917. It has since been confirmed by the examination of several hundred specimens. Collophane is an amorphous substance of somewhat variable composition, but its properties are sufficiently distinctive to regard it as a definite mineral species, as has been shown by the writer in a recent paper.[3]

Identity of the Material of Fossil Bone with Collophane

That the material of fossil bone is collophane is proved by the following comparison of properties:

Collophane	Fossil bone
Amorphous.	Amorphous.
Color, variable.	Color, variable.
H., 3-5.	H., 3-5.
Specific gravity, 2.6-2.92.	Specific gravity, 2.6-2.94.
Index of refraction, 1.593-1.627.	Index of refraction, 1.573-1.621.
Birefringence, *nil* to very weak.	Birefringence, *nil* to very weak.
Fuses on edges and turns white.	Fuses on edges and turns white.
Gives water in the closed tube and turns dark gray or black.	Gives water in the closed tube and turns dark gray or black.
Soluble in HNO_3 with effervescence.	Soluble in HNO_3 with effervescence.
Chem. Comp., 3 $Ca_3(PO_4)_2$.*n* Ca (CO_3,F_2,O,SO_4) $(H_2O)_x$ $n=1$ to 2.	Chem. Comp., 3 $Ca(PO_4)_2$.*n* Ca (CO_3,F_2,O,SO_4) $(H_2O)_x$ $n=1$ to 1.8
Small amounts of Al, Fe, and Mg may replace Ca.	Small amounts of Al, Fe, and Mg may replace Ca.

Fossil bone gives tests which are practically identical with those for the collophane of phosphorites. The only way to distinguish it from other kinds of collophane is by the megascopic or microscopic structure. Although fossil bone is of organic origin, the material of which it is composed is largely inorganic. In most cases the organic matter present probably amounts to not more than a per cent or so. If the principal constituent of phosphorite or so-called phosphate rock is to be considered

[1] Scott, for example, in his "Introduction to the study of geology," 2d edition, p. 520, 1907, says: "A silicified bone or tooth, or bit of wood, differs from the original only in weight, colour, and hardness. . . ."

[2] Journal of Geology, vol. xxv, 1917, p. 531.

[3] American Journal of Science (5), vol. iii, 1922, pp. 269-276.

a definite mineral, then it is clear that the material of fossil bones must also, for it is "a naturally occurring homogeneous, inorganic substance of definite or fairly definite chemical composition and with characteristic physical properties."[4] The name collophane[5] may be used for this amorphous hydrous calcium carbonate-phosphate.

With these preliminary remarks in mind, the results of my study of fossil bone may be presented.

Material used in this Investigation

The material used in this investigation consists of about 300 fossil bones from 22 different States of the United States and from the following foreign countries: Canada, Venezuela, Ecuador, Brazil, Argentina, England, France, Germany, Egypt, South Africa, Syria, Mongolia, China, and Japan. Geologically, the fossil bones or bone-like plates range from the Ordovician up through all the major divisions to the Recent. Nearly all of the important zoological groups of vertebrates are represented: ostracoderms, ganoids, selachians, dipnoans, arthrodires, teleosts, a few amphibians, many reptiles (rhynchocephalians, pythonomorphs, sauropterygians, chelonians, crocodilians, dinosaurs, and pterosaurs), and many mammals (multituberculates, cetaceans, sirenians, artiodactyls, perissodactyls, rodents, carnivores, and primates).

About 170 specimens of fossil bones were studied in thin-sections; about half of these and 150 other bones were examined in crushed fragments. The thin-sections show the character of the collophane and also the relation of the collophane to the associated minerals, but the fragments show almost equally well the characteristic features of collophane and in addition may be used to determine the index of refraction by the indirect immersion method.

With the large and varied amount of material generously placed at my disposal by many friends, gratefully acknowledged on page 552, it is believed that it is safe to generalize as to the nature of fossil bone.

Chemical Composition of the Collophane of Fossil Bone

The collophane of fossil bone free from associated minerals, such as calcite, quartz, chalcedony, etcetera, is soluble in cold dilute nitric acid with fair effervescence. The solution is usually pale brown and cloudy from the organic matter present. The hot nitric acid solution gives a good test for the phosphate radical with an excess of ammonium molyb-

[4] A. F. Rogers: Introduction to the study of minerals and rocks, 2d edition, p. 1, New York, 1921.

[5] Collophane is simpler and more euphonious than the alternative name, collophanite.

date (a finely divided yellow precipitate soluble in ammonium hydroxid) and also a test for calcium with dilute sulfuric acid and 50 per cent ethyl alcohol. The sulfuric acid test is a better one for calcium than the usual ammonium oxalate test, for when the original acid solution is made alkaline with ammonium hydroxid preparatory to making the calcium test the calcium is precipitated as calcium phosphate.

Small amounts of iron, aluminum, and magnesium may be present and also fluorin and the sulfate radical.

The closed tube tests also show the presence of a relatively large amount of water, from 3 to 5 per cent, and some organic matter.

A number of analyses of fossil bones have been made by Fremy[6] and by Carnot,[7] but since the homogeneity of the material was not determined by microscopic investigation the analyses have little value. The large excess of calcium carbonate found in some cases is in all probability due to admixed calcite, which, according to the writer's investigations, is present in about half of the specimens examined. A few scattering analyses of fossil bone have been found in the literature, but they are incomplete and there is no guarantee of the purity of the material.

Complete analyses of the collophane of fossil bone free from other materials are needed to determine its chemical composition. It is very difficult to find the collophane free from other substances, and the latter are so intimately associated that mechanical separation is very difficult and often impossible.

Three specimens of fossil bone practically free from foreign substances were finally found. These have been analyzed by Mr. K. S. Boynton, under the writer's direction. They are listed below and, except for organic matter, they are believed to be practically complete. Microscopic examination shows nothing to be present with the collophane except traces of earthy matter and possibly a few minute sand grains. The insoluble material amounts to only 0.1 to 0.2 per cent. Not a trace of calcite could be detected in thin-sections of these three fossil bones.

The three analyzed fossil bones are as follows:

A. Cetacean rib from the Pliocene of Brewster, Florida. Pale brown. Specific gravity $= 2.885$; $n^8 = 1.609 \pm .001$.

This specimen was furnished by Dr. E. H. Sellards, formerly State Geologist of Florida.

B. *Gorgosaurus* vertebra from the Belly River (Upper Cretaceous) beds of Alberta. Rather dark brown. Specific gravity $= 2.941$; $n = 1.621 \pm .001$.

This specimen was furnished by the American Museum of Natural History.

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[6] Ann. de chemie et de physique (3), vol. xliii, 1855, pp. 47-107.

[7] Ann. des Mines (9), vol. iii, 1893, pp. 155-195.

[8] The symbol n here refers to the index of refraction.

C. *Diceratherium* vertebra from the Lower Harrison (Miocene) beds of Nebraska. Colorless. Specific gravity = 2.822; $n = 1.601 \pm .001$.

This specimen was furnished by the American Museum of Natural History.

Analyses of Fossil Bone by K. S. Boynton

	CaO	MgO	Al_2O_3	Fe_2O_3	P_2O_5	CO_2	SO_3	F_2	H_2O	Insol.	Total[9]
A.....	48.88	tr.	2.83	0.82	41.34	2.36	0.45	tr.	3.26	0.10	100.04
B.....	48.51	tr.	0.98	2.00	37.79	4.73	0.03	0.93	3.47	0.20	99.22
C.....	49.27	tr.	0.08	0.62	37.35	5.55	0.10	1.17	4.83	0.20	98.81

The iron has been calculated as ferric oxid, but on account of the organic matter present its state of oxidation is uncertain. A part of the water (1.46, 1.26, and 2.15 in A, B, and C respectively) is given off below 110° centigrade, but in an amorphous substance, such as collophane, the amounts of water given off below and above this temperature have no special significance.

On dividing the percentages by the formula weights, the following ratios are obtained:

Ratios of Constituents in Fossil Bone

	CaO	Fe_2O_3	Al_2O_3	P_2O_5	CO_2	SO_3	F_2	O	H_2O
A.....	.872	.015	.083	.291	.054	.006	....	.037	.181
B.....	.864	.038	.029	.266	.107	....	.025	....	.194
C.....	.876	.011	.002	.263	.126	.001	.031	....	.267

On combining the bases with acid radicals (iron and aluminum having been included with calcium), they yield the following:

A. $3\,Ca_3(PO_4)_2.0.55\,CaCO_3.0.06\,CaSO_4.0.38\,CaO.1.86\,H_2O$.
B. $3\,Ca_3(PO_4)_2.1.20\,CaCO_3.0.28\,CaF_2.2.18\,H_2O$.
C. $3\,Ca_3(PO_4)_2.1.43\,CaCO_3.0.35\,CaF_2.3.03\,H_2O$.

If the carbonate, sulfate, fluorid, and oxid are combined, we have the following:

A. $3\,Ca_3(PO_4)_2.0.99\,[Ca(CO_3,SO_4,O_x)].1.86\,H_2O$.
B. $3\,Ca_3(PO_4)_2.1.48\,[Ca(CO_3,F_2,SO_4)].2.18\,H_2O$.
C. $3\,Ca_3(PO_4)_2.1.78\,[Ca(CO_3,F_2SO_4)].3.03\,H_2O$.

The general formula of collophane, then, is:

$3\,Ca_3(PO_4)_2.n\,Ca(CO_3,F_2,SO_4,O).(H_2O)_x$, where n has the limiting values of 1 and 2 and x is also variable.

Fossil bone, like other forms of collophane, may be regarded as a solid

[9] Less oxygen equivalent of fluorin.

solution of calcium carbonate, and smaller amounts of calcium fluorid, sulfate, and oxid, in tricalcium phosphate.

Organic matter is also present in the three fossil bones analyzed, but the amount can not be large, probably not over one per cent or so, as the summation of constituents is close to a hundred per cent.

Collophane is not a definite chemical compound, for the composition varies, but the variation is within certain limits, as indicated by the formula. It often approaches in chemical composition the crystalline mineral dahllite, $3\,Ca_3(PO_4)_2.CaCO_3$, of which it may be regarded as the amorphous equivalent.

Microscopic Structure of Fossil Bone

The microscopic structure of bone is very well preserved in the fossil condition, even in the older Mesozoic and Paleozoic bones. This has been noted by previous observers.[10] In solid bone the Haversian canals with concentric osseous lamellæ may often be observed, as, for example, in plate 26, figure 1. Lacunæ, the most characteristic histologic feature, are visible in almost every thin-section studied and are also apparent in small fragments when examined with the compound microscope. Plate 26, figure 1, plate 27, figures 1 and 4, and plate 28, figure 3, show the presence of lacunæ. Even the minute canalculi surrounding the lacunæ are sometimes found with high magnifications, as shown in plate 28, figure 3. (See especially the upper left and lower right corners.)

Occasionally the above mentioned histologic structures seem to be entirely lacking. Such is the case of the fossil bone illustrated in plate 29, figure 1.

Color and Pleochroism of Fossil Bone

In thin-sections, about 0.03 to 0.04 millimeter thick, the collophane of fossil bone is usually colored, but many specimens are practically colorless. The color varies considerably in different specimens, and sometimes from spot to spot in the same specimen. The color in thin-sections is usually some tint or shade of brown. The hue varies with a common tendency toward yellow brown. The color seems to be due largely to an organic pigment of some kind. In some cases the color may be due in part to iron, as, for example, in the *Gorgosaurus* of analysis B, on page 538, which contains two per cent of ferric oxid.

In a thin-section of a spine of a Permian reptile (*Edaphosaurus* or

[10] A. L. L. Seitz: Nova Acta Abh. d. Kaiserl. Leop.-Carol. Deutscher Akad. d. Naturforscher., vol. lxxxvii, no. 2, 1907, pp. 231-370.
R. L. Moodie: Paleopathology. University of Illinois Press, Urbana, Illinois, 1923.

related form) from Texas the collophane showed distinct pleochroism from pale yellow to deeper yellow, the latter when the osseous lamellæ were perpendicular to the vibration plane of the lower nicol. Now pleochroism is highly characteristic of certain colored crystals, but this is probably the first record of pleochroism in an amorphous substance.[11] Pleochroism, like double refraction, is a vectorially continuous property and, as Friedel[12] has emphasized, such properties are not limited to crystalline substances.

Index of Refraction of Collophane

One of the most characteristic properties of a substance that transmits light is its index of refraction. In fossil bone the index of refraction may be determined easily and rapidly by the indirect immersion method which has been used so extensively by mineralogists the last decade or so.

A series of liquids with known indices is prepared. For general mineralogical work these range from 1.45 to 1.74 and differ by 0.01. For collophane the range is 1.57 to 1.63, and so the liquids needed are those with the following indices of refraction: 1.57, 1.58, 1.59, 1.60, 1.61, 1.62, and 1.63. These liquids may be prepared by mixing clove oil and alpha-monobromnapthalene (or alpha-monochlornapthalene) in varying proportions).[13] The indices of refraction of the liquids are determined by an Abbé or Pulfrich refractometer.

Fragments are embedded first in one liquid, then in another, until the index is determined within certain limits. With collophane it is well to begin with the liquid 1.60. A few fragments are immersed in the liquid on a glass slip, placed on the stage of a microscope, and the iris diafram[14] of the substage partially closed. After focusing sharply on a fragment of collophane (the collophane is distinguished from associated minerals by its low relief, optically isotropic character or weak double-refraction, and presence of lacunæ), the microscope tube is suddenly, but slightly, raised. A white line or illuminated zone appears toward the substance with the higher index of refraction. If it appears inside the mineral, the mineral has an index greater than 1.60; if it appears outside the mineral, the index is less than 1.60. The explanation of this phenomenon may

[11] Prof. R. J. Colony, of Columbia University, has called the writer's attention to pleochroism of "fish remains" (identified as collophane by the writer) in a Cretaceous limestone from the region of the Dead Sea, Palestine.

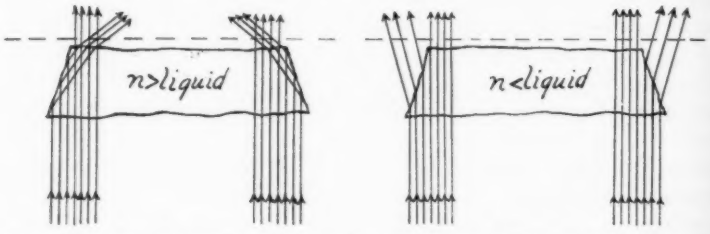
[12] Leçons de Cristallographie, Paris, 1911, pp. 143-144.

[13] Prepared liquids may be obtained from Dr. A. C. Hawkins, 154 Nunda Boulevard, Rochester, New York.

[14] In the absence of an iris diafram, a simple diafram may be made by punching a hole about 4 millimeters in diameter through a piece of cardboard which may be attached to the lower part of the substage by a bit of wax.

be shown by a consideration of figures 1 and 2. Light rays after traversing a substance embedded in a liquid will on emergence be totally reflected in case the substance has a greater index than that of the liquid (see figure 1). If, on the other hand, the substance has a smaller index than the liquid, the light rays will enter the liquid and will be refracted (see figure 2). If the focus is slightly above the mineral fragment, as shown by the dotted line, there will be a concentration of light toward the fragment in the first case and away from the fragment in the second case. If the fragment is small enough, the fragment as a whole, not simply the border, is either illuminated or darkened.

By mixing two equal size drops on a glass slip, liquids of intermediate indices, such as 1.595, 1.605, etcetera, may be obtained. Thus the index



FIGURES 1 and 2.—*Explanation of the indirect immersion Method of determining the Index of Refraction*

can be determined to within 0.0025 of the correct value, or, taking into account the fact that the drops may not be of exactly equal size, to within 0.003. In case the liquid and the fragment have almost the same value, the border of the fragment will appear colored on account of dispersion. In this event it is advisable to use monochromatic light. The light filtered through a saturated solution of potassium bichromate, about 1 centimeter thick, approaches orange-yellow monochromatic light, and thus saves the necessity of using a dark room. A Wratten E filter number 22 (Eastman Kodak Company) is even better for this purpose.

About 250 determinations of the index refraction of the collophane of fossil bone have been made. The values, which may be expressed 1.570–1.575, etcetera, or $1.573 \pm .003$, etcetera, range from about 1.573 to about 1.623. The following are the results:

Index of refraction	Number of examples
1.570–1.575	2
1.575–1.580	2
1.580–1.585	3
1.585–1.590	8
1.590–1.595	13
1.595–1.600	49
1.600–1.605	62
1.605–1.610	70
1.610–1.615	30
1.615–1.620	9
1.620–1.625	2
Total	250

The above values have been plotted to form the frequency curve of figure 3, in which the abscissæ represent the indices of refraction and the ordinates the number of determinations of each value. The curve is a skew curve with the mode at 1.6075, the arithmetic mean at 1.6027, and

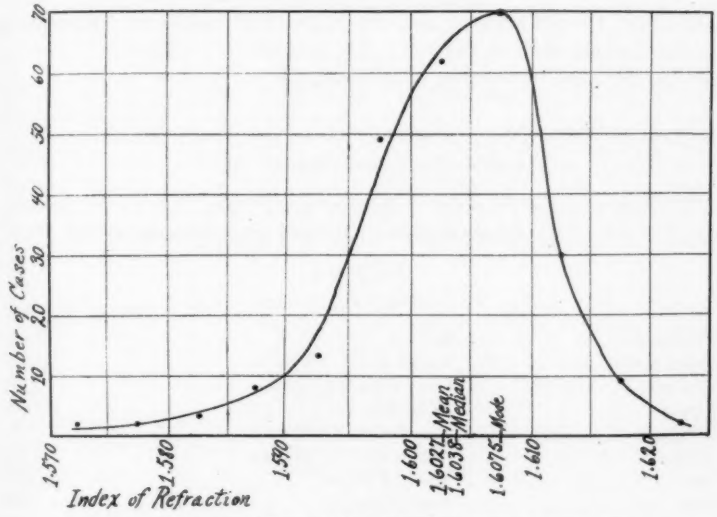


FIGURE 3.—*Frequency Curve of the Refractive Index of Fossil Bone*

the median[15] at 1.6038. The index of refraction of 88 per cent of the fossil bones examined lies between 1.593 and 1.613 and about half of them between 1.600 and 1.610.

[15] The median value was determined by the formula given in "Elements of statistical method," by W. I. King, New York, 1912, p. 129.

Specimens of fossil bone with a low index of refraction are probably somewhat porous, but, aside from this, the index of refraction of collophane is variable because of variability in the chemical composition. All the chemical constituents, including water and organic matter, vary in different specimens. The organic matter probably lowers the index of refraction, for in 20 specimens of collophane not formed from bone the mode is 1.6175 and the arithmetic mean, 1.612. In the absence of many complete analyses, it is not possible to correlate the index of refraction with the chemical composition, but from the three analyses given on page 539, it would seem that iron is probably the most important single factor influencing the refractive index. In figure 4 the index of refraction is plotted against the iron content. The relation is probably complicated, but the influence of the iron is unmistakable.

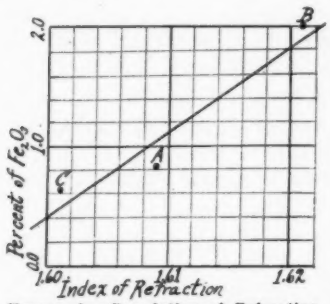


FIGURE 4.—*Correlation of Refractive Index of Fossil Bone with Iron Content*

LIST OF REFRACTIVE INDICES OF SOME FOSSIL BONES ARRANGED ACCORDING TO GEOLOGICAL AGE [16]

The tabulation given here includes available fossil bones, 83 in number, for which both the zoological group and geological age are known.

Pleistocene

Name	Locality	Index of refraction [17]
Platygonus	Kansas	1.573
Bison ferox	Snake River, Idaho	1.573
Elephant	Lane County, Kansas	1.587
Equus	Nebraska	1.597
Cetacean	San Pedro, California	1.597
Whale	San Pedro, California	1.597
Deer	Vero, Florida	1.597
Deer	Vero, Florida	1.603
Deer	Ocala, Florida	1.607
Deer	Vero, Florida	1.607

[16] The index of refraction of recent bone (weathered bone from which most of the organic matter has disappeared) is 1.563±.003.

[17] These values are correct to within three figures in the third decimal place with the exception of *Diceratherium* and *Gorgosaurus*, which are correct to within one figure in the third place.

Pliocene

Name	Locality	Index of refraction
Teleoceras	Kansas	1.603
Mammal	Florida	1.603
Whale	Near Stanford University, California	1.603
Zerobates	(Loup Fork) Kansas	1.603
Whale	Los Angeles, California	1.607
Rhinoceros	Phillips County, Kansas	1.607
Mammal	Florida	1.607
Tomistoma americana	Brewster, Florida	1.613

Miocene

Diceratherium	Nebraska	1.601
Eporeodon	South Dakota	1.603
Edentate	(Santa Cruz) Patagonia	1.603
Xyne grex	Lompoc, California	1.607
Mammal	Alum Bluff, Florida	1.607
Hapalops (?)	Rio Gallegos, Patagonia	1.607
Turtle	Gadsden County, Florida	1.613
Desmostylus	Santa Clara County, California	1.617

Oligocene

Oreodon	Converse County, Wyoming	1.593
Oreodon	Colorado	1.597
Arsinoïtherium	Egypt	1.607
Caenopus	(White River) South Dakota	1.607
Oreodon	Converse County, Wyoming	1.607
Oreodon	South Dakota	1.613
Titanotherium	(White River) South Dakota	1.613

Eocene

Diplomystis	Green River, Wyoming	1.583
Paleotherium	France	1.593
Whale	Near Lompoc, California	1.597
Periptychus	(Torrejon) New Mexico	1.597
Phenacodus	(Wasatch) Wyoming	1.597
Coryphodon curvicristus	Wyoming	1.607
Polymastodon	(Puerco) New Mexico	1.613
Pelycodus	Bighorn Basin, Wyoming	1.617

Cretaceous

Clidastes velox	Logan County, Kansas	1.587
Clidastes pumilus	(Niobrara) Kansas	1.587
Protostega gigas	(Niobrara) Kansas	1.587
Toxochelys	(Niobrara) Logan County, Kansas	1.587
Pterodactyl	Kansas	1.593
Brachysaurus overtoni	(Fort Pierre) South Dakota	1.597
Tylosaurus	Kansas	1.603
Protosphyraena	Kansas	1.603

Name	Locality	Index of refraction
Xiphactinus (Portheus)	Kansas	1.603
Triceratops	Niobrara County, Wyoming	1.607
Triceratops	(Laramie) Kansas	1.607
Struthiomimus	Iren Dabasu, Mongolia	1.607
Lepidosteus (scales)	Cow Island, Montana	1.613
Trachodon	Cow Island, Montana	1.613
Aspidorestes	Judson Creek, Montana	1.613
Plesiosaur	Cow Island, Montana	1.613
Plesiosaur	(Niobrara) Kansas	1.613
Champsosaurus	(Belly River) Alberta	1.613
Trachodont	(Belly River) Alberta	1.617
Camptosaurus	Como, Wyoming	1.617
Gorgosaurus	(Belly River) Alberta	1.621
	Jurassic	
Fish	Lebanon Mountains, Syria	1.587
Sauropod dinosaur	(Morrison) Wyoming	1.607
Dinosaur	Wyoming	1.613
	Triassic	
Semionotus fultus	Boonton, New Jersey	1.583
Reptile	Shasta County, California	1.607
	Permian	
Naosaurus	Texas	1.607
Eryops	Bellmont, Oklahoma	1.613
Reptile	South Africa	1.617
	Carboniferous	
Amphibian	Linton, Ohio	1.613
	Devonian	
Arthrodire plate	Cleveland, Ohio	1.597
Arthrodire plate	Cleveland, Ohio	1.603
Arthrodire plate	Cleveland, Ohio	1.607
Bothriolepis canadensis	Migouaska, Quebec	1.613
Eusthenopteron foordi	Migouaska, Quebec	1.613
Ctenacanthus formosus	Cleveland, Ohio	1.613
Fish	Bradford, Pennsylvania	1.613
Arthrodire plate	Monroeville, Ohio	1.623
	Silurian	
Machaeracanthus peracutus	Clifton, New York	1.597
Fish	Erie County, New York	1.607
	Ordovician	
Ostracoderm (?)	Wyoming	1.607
Astraspis (ostracoderm)	Canon City, Colorado	1.613

This tabulated list brings up the interesting question as to the possible correlation of the index of refraction of fossil bone with the geological age. While the mean index of the Pleistocene bones is low (1.594) and that of the Paleozoic rather high (1.611) when compared with the general mean (1.6027) of all the bones, the correlation is in general very imperfect. The Cretaceous bones, for example, show a range from 1.587, which is near the lowest value found, up to 1.621, which is about the maximum value. Geological age probably has some influence on the index of refraction, but it is of minor importance. The evidence seems to indicate that a bone becomes fossilized in a comparatively short time, geologically speaking, and after that further changes take place very slowly. The ossified exoskeletons of the Ordovician ostracoderms from Colorado and Wyoming have the same index of refraction as some of the fossil bones of Tertiary age.

Even though the index of refraction can not be correlated with geological age, it might be well for the paleontologist in his description of a vertebrate fossil to determine and record the index of refraction of the collophane of the fossil bone concerned.

Double Refraction of Collophane

Like other amorphous minerals, the collophane of fossil bone usually shows weak double refraction.[18] The double refraction is doubtless due to strain. It lacks the uniformity characteristic of crystalline substances and the extinction is often wavy, as is illustrated in plate 26, figure 2. (Plate 26, figure 1, taken in ordinary light, is given for comparison.) The double refraction varies from nothing up to about .005 in different specimens; the values were obtained by determining the thickness of sections which contain quartz, either in the form of sand grains (plate 28, figure 1) or as a crystalline cavity filling (plate 27, figure 3).

Longitudinal sections of fossil bone usually show extinction parallel to the length of the bone. In such cases the faster ray is usually parallel to the length of the bone, but rarely the slower ray has this direction. In a Mosasaur bone from the Kansas Cretaceous, portions of the collophane have alternately positive and negative elongation with intermediate, rather indefinite isotropic zones.

Pseudospherulitic Structure

Around Haversian canals, vascular, and other larger cavities or structures, the collophane often shows an apparent spherulitic structure be-

[18] See article by the author. Jour. Geol., vol. xxv, 1917, pp. 515-541.

tween crossed nicols. These are illustrated in plate 27, figures 1 and 2. These structures, which are due to concentric layers and not to radially disposed fibers, may be called *pseudo-spherulites*. In circular sections pseudo-spherulites and true spherulites can not be distinguished, but in elliptic sections the arms of the dark cross of a pseudo-spherulite are not at right angles to each other as they are in a true spherulite. This difference has been emphasized by Cole.[19] The pseudospherulitic character of collophane is well shown in plate 27, figure 2,[20] and is additional proof, or at least evidence, of the amorphous nature of collophane.

Associated Minerals

Ten or a dozen minerals are found in close association with the collophane of fossil bone. Of these calcite is by far the most common; in fact, it was observed in about half of the thin-sections examined. The calcite usually occurs as a cavity filling in cancellated bone or in the medullary cavity of long bones. Specimens are illustrated in plate 26, figure 4; plate 27, figure 4; plate 28, figure 4; and plate 29, figures 1 and 2.

Next to calcite, the most common associates of collophane are the silica minerals, quartz, chalcedony, and opal. The silica, however, is not often a replacement of bone. Nearly all of the so-called silicified bones are simply specimens in which the cavities of the bone have been filled with these minerals. Illustrations of these are furnished by plate 27, figures 3 and 4, and plate 28, figure 2.

Dolomite, barite, and pyrite are not uncommon associates of the collophane in fossil bone. Dolomite may be recognized by the euhedral crystals, as shown in plate 28, figure 2. Pyrite is present in the fossil bones of *Dinichthys* (see plate 26, figure 3) and in the spine of *Ctenacanthus* of the Devonian and Carboniferous, respectively, of Ohio. It was also noted in fossil bone from Oakville, Washington. Barite was noted in the cavities of mosasaur and plesiosaur bones from the Cretaceous of Kansas and also in *Cladodus* and *Dinichthys* bones from Ohio. Aragonite in spherulites was identified in a bone from the Pliocene of San Gregorio, Santa Cruz County, California.

Indefinite iron oxids are found associated with the bones from the Permian Red Beds of Oklahoma and Texas, and a bone from Seabright, Santa Cruz County, California, contains black earthy manganese dioxid in cavities.

[19] Aids in Practical Geology, 6th ed., London, 1909, p. 149.

[20] These are cross-sections of elongated structures, as has been pointed out to me by Mr. F. K. Morris. Hence they are more properly designated by the term pseudo-axiolites.

Collophane is found as a cavity filling of fossil bone from the phosphatic marl beds of South Carolina. Except for the absence of lacunæ, the collophane in the cavities is indistinguishable from the collophane of the fossil bone.

There is little evidence of the migration of phosphatic solutions in and around fossil bone. One of the few examples is the occurrence of a small amount of stalactitic collophane in the cavity of a large tooth from the Miocene (Fernando formation) of the Puente Hills, near Los Angeles, California. Strange to say, phosphate minerals other than collophane are very rare in fossil bones. The only ones found by the writer are dahllite and wavellite.

One would expect the collophane of fossil bone to go into solution and to recrystallize in the form of dahllite, $3[Ca_3(PO_4)_2].CaCO_3$, which, next to collophane itself, is the most common mineral found in phosphorites or so-called phosphate rocks, but this rarely happens. The amorphous condition, although theoretically unstable, may persist for an exceedingly long period. I have observed dahllite, the crystalline equivalent of collophane, in fossil bones from two different localities, one in the Miocene of San Luis Obispo County, California, and the other in the Permian of Texas.

In thin-sections of spines of a Permian reptile from Texas, kindly lent to me by Dr. R. L. Moodie, minute crystals of dahllite have been recognized. They occur in cavities of fossil bone associated with calcite, as represented in plate 28, figure 4. They appear as minute, optically negative, tabular crystals with weak double-refraction. In most spots they appear as microcrystalline aggregates, which probably have been crystallized out of an amorphous mass.

In a fossil rib (cetacean?) from the Pliocene of Brewster, Florida, furnished by Dr. E. H. Sellards, spherulites of wavellite, an aluminum phosphate, were found. In this connection it is interesting to note that an analysis (A, page 539) of one of these bones, free from wavellite, shows aluminum to be present to the amount of 2.83 per cent of Al_2O_3.

The minerals enumerated above occur for the most part as cavity fillings in the bone. There is evidence, however, of the forcing apart of the collophane by calcite and chalcedony. Plate 26, figure 4, illustrates a Pliocene or Pleistocene bone breccia, collected by Mr. Harold Hannibal, from the top of Gabilan Peak, San Benito County, California. Here a cross-section of a long bone, probably of a rodent, has been forced apart by the crystallization of the calcite. This seems to confirm the observations of Taber[21] on the pressure exerted by the "force of crystallization,"

[21] Proc. Nat. Acad. Sci., vol. iii, 1917, pp. 297-302.

but whether it has been of much importance in the formation of mineral veins is another question.

Replacement of Collophane by other Minerals

While most of the minerals associated with collophane in fossil bone are cavity fillings, or the cementing material of fragments of bone, there is undoubted evidence of the replacement of collophane by other minerals. Of these replacing minerals the only one that is at all common is calcite. Plate 29, figures 1-3, illustrate the replacement of collophane by calcite. In figures 1 and 2 the replacement is slight; in figure 2 the calcite occurs in such thin films that it shows bright interference colors of the first and second orders.

An extreme case of replacement of collophane by calcite is shown in figure 3, which is a cross-section of a long bone in a Pleistocene bone breccia from the Samwell Cave, Shasta County, California, from the collections of the University of California. Now this is a reversal of the ordinary course of events, for it is a well known fact, demonstrated by Reese,[22] that calcium phosphate is less soluble than calcium carbonate. Many varieties of phosphorite or so-called phosphate rocks are formed by the replacement of limestones. The Florida phosphorites often contain phosphatized mollusc shells. The original collophane (Kollophan), described by Sandberger from the island of Sombrero, in the West Indies, was formed by the action of phosphatic solutions from overlying guano on an elevated coral reef.

The replacement of calcium phosphate by calcium carbonate may be explained by the law of mass-action of chemistry. With a large excess of calcium carbonate available, as would be the case in a limestone cavern, the calcium phosphate might be replaced in time. In fact, in most of the rocks in which fossil bones occur, calcium carbonate greatly predominates over calcium phosphate, and hence we often find the collophane partly replaced by calcite.

Of all the fossil bones, about 300, examined by the writer, only three were found to be silicified. A thin-section of one of them, a specimen of unknown age, but probably Tertiary, from near Stanford University, collected by one of my students, Mr. F. G. Gibson, is shown in plate 29, figure 4. Fragments of collophane are cemented by chalcedony and some of the collophane has been replaced by quartz. In places the lacunæ are as well preserved in quartz as in the original collophane.

In another silicified bone from Scott's Valley, Santa Cruz County, California, the replacing mineral is found to be opal.

[22] Amer. Jour. Sci. (3), vol. xliii, 1892, p. 402.

The opalized bones from White Cliffs, New South Wales, are not true replacements of bone by opal, for they do not show the internal structure of bone. They are doubtless due to the filling of cavities from which the bone substance had disappeared.

Fossilization of Bone

An analysis of a recent bone is listed below for comparison with the analyses of fossil bones given on page 539.

Analysis of Recent Bone

$CaO = 36.80$; $MgO = 0.61$; $P_2O_5 = 28.10$; $CO_2 = 3.00$; Ossein (Collagen) = 26.00; H_2O, F, etcetera, = 4.69

During fossilization the specific gravity increases from 1.9–2.0 up to 2.7–2.9, and the index of refraction increases from about 1.56 to 1.58–1.62.

It is evident that the fossilization consists in the removal of most of the organic matter and an increase in the amount of calcium phosphate and calcium carbonate. Recent bone consists of a substratum of ossein or collagen which is permeated with the calcium compounds. After death and decay of the animal the organic matter gradually disappears. Weathered bones found in the fields are more or less brittle because of the removal of a part of the organic material. Weathering seems to leave the bone in a somewhat porous condition, and when covered over with sediments percolating solutions deposit calcium phosphate, calcium carbonate, and small amounts of other substances. The source of the extraneous calcium phosphate may be in part due directly to the weathering of other bones, but it is more probable that most of it is derived from the general circulation of ground water.[23] It seems probable that fossil bones are able to collect small amounts of calcium phosphate from percolating solutions, and this process seems to be an effective means of concentrating calcium phosphate. The tricalcium phosphate locked up in fossil bones must in the aggregate be considerable.

A little of the phosphatic material subsequently may be released in the replacement of the collophane by calcite, but this is probably small in amount. There is little evidence of the migration of calcium phosphate away from fossil bones.

[23] For a discussion of the circulation of phosphatic solutions, see paper by E. Blackwelder. Amer. Jour. Sci. (4), vol. xlii, 1916, pp. 285-298.

Conclusions

Fossil bones consist for the most part of the amorphous mineral, collophane, which is also the principal constituent of phosphorite or so-called phosphate rock. The chemical formula of collophane is

$$3Ca_3(PO_4)_2.nCa(CO_3)(H_2O)_x,$$

in which calcium is partially replaced by iron, aluminum, and magnesium and the carbonate radical by fluorin, the sulfate radical, and oxygen, and where n has the limiting values 1 and 2 and x is also indefinite.

Fossil bone usually retains the original structure of Recent bone. Lacunæ are nearly always visible in fossil bone, and occasionally canalieuli may be recognized.

The index of refraction of the collophane varies from 1.573 to 1.621, but of those examined about half lie between 1.600 to 1.610. Although amorphous, collophane usually shows double refraction. Pseudospherulitic structures are not uncommon.

Minerals associated with the collophane of fossil bone include calcite, quartz, chalcedony, opal, dolomite, aragonite, barite, pyrite, collophane, dahllite, and wavellite. These minerals usually occur as cavity fillings. Collophane, however, is often replaced by calcite, but very rarely by quartz or opal. Contrary to general opinion, silicified bones are exceedingly rare.

The fossilization of bone consists of the filling of porous bone, from which the organic matter of the original bone has been removed during weathering, by calcium phosphate, calcium carbonate, and small amounts of other substances. This change produces a marked increase in specific gravity and index of refraction.

There is not much evidence of the migration of phosphatic solutions in and around fossil bone, but occasionally collophane, dahllite, and wavellite are found as cavity fillings.

The geological age of a fossil bone can not be determined from the character of the collophane.

Acknowledgments

This study has been made possible by the generous contribution of material by a score or more of individuals. For the donation of fossil bones, I am indebted to the following named gentlemen: Mr. S. F. Adams, Dr. R. S. Bassler, Prof. E. B. Branson, Mr. C. M. Carson, Prof. E. C. Case, Mr. W. J. Classen, Mr. Grant Corby, Mr. R. B. Evans, Mr. F. R. Gibson, Prof. J. Z. Gilbert, Mr. H. Hannibal, Prof. Harold Heath,

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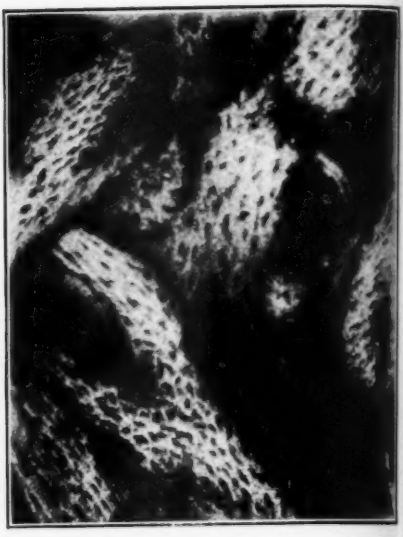

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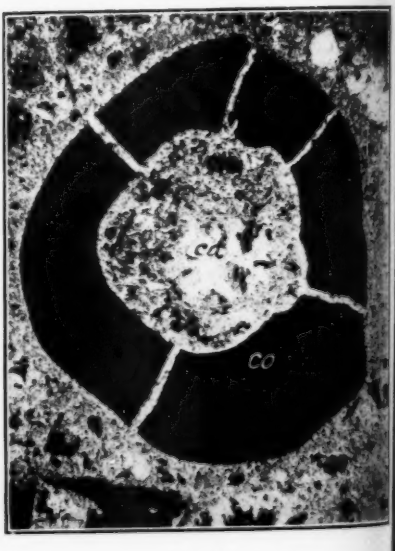


4

PHOTOMICROGRAPHS OF FOSSIL BONES

Mr. S. C. Herold, Prof. T. J. Hoover, Mr. C. Y. Hsieh, Prof. J. E. Hyde, Dr. D. S. Jordan, Prof. R. S. Lull, Mr. H. T. Martin, Dr. W. D. Matthew, Dr. J. C. Merriam, Dr. R. L. Moodie, Mr. F. K. Morris, Mrs. T. S. Oldroyd, Mr. R. H. Palmer, Col. W. A. Roebling, Dr. R. Ruedemann, Dr. F. R. Sandt, Dr. E. H. Sellards, Prof. J. P. Smith, Prof. J. O. Snyder, Dr. Chester Stock, Prof. Stephen Taber, Mr. H. D. Sutliff, Col. William Thompson (through Dr. G. F. Kunz), Dr. A. J. Tieje, Mr. V. W. Triplett, Mr. W. K. Vickery, Mr. M. Vonsen, Prof. Stuart Weller, and Prof. H. Yabe.

I am also indebted to Dr. R. L. Moodie for the loan of a collection of about 100 thin-sections of fossil bones.

Dr. J. E. Coover has kindly helped me with the statistical work represented by the frequency curve of page 543.

Valuable suggestions have been given me by Dr. W. K. Gregory, who, as secretary of the Williston Memorial Committee, read the manuscript of this paper, which was originally intended for publication in the Williston Memorial Volume.

Explanation of Plates

Plate 26.—*Photomicrographs of Fossil Bones*

(co = collophane; ca = calcite; p = pyrite)

Figure 1.—Section of mammal bone from pebble phosphate deposits (Pliocene) of Florida, showing Haversian canals and lacunæ. All collophane. (× 56 diameters.)

Figure 2.—Same as figure 1, but taken with crossed nicols. The wavy extinction is shown in the center of the photograph. All collophane. (× 56 diameters.)

Figure 3.—Section of maxillary of *Dinichthys* from Ohio, with cavity filling of calcite and pyrite. Crossed nicols. (× 74 diameters.)

Figure 4.—Cross-section of long bone (probably a rodent) in bone breccia from Gabilan Peak, San Benito County, California, with calcite as the cementing material. Crossed nicols. (× 54 diameters.)

PLATE 27.—*Photomicrographs of Fossil Bones*

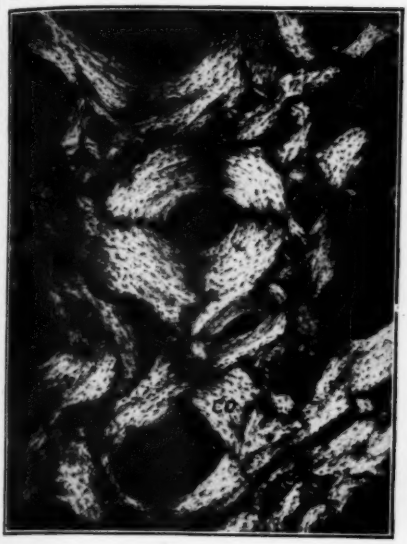
(co = collophane; ca = calcite; ch = chalcedony; q = quartz; o = opal)

FIGURE 1.—Section of cancellated bone of *Diceratherium* from the Miocene of Nebraska, showing pseudospherulitic character. All collophane. Crossed nicols. (× 60 diameters.)

FIGURE 2.—Section of tooth of *Mazodus* from the Cuyahoga shale (Mississippian) of Berea, Ohio, showing pseudospherulites (pseudoaxiolites). All collophane. Crossed nicols. (× 74 diameters.)

FIGURE 3.—Section of cancellated fish bone from Oregon, showing double refraction of collophane and cavity filling of chalcedony and quartz. Crossed nicols. (× 44 diameters.)

FIGURE 4.—Section of bone from the John Day region of Oregon, with cavity filling of opal and calcite. (× 55 diameters.)



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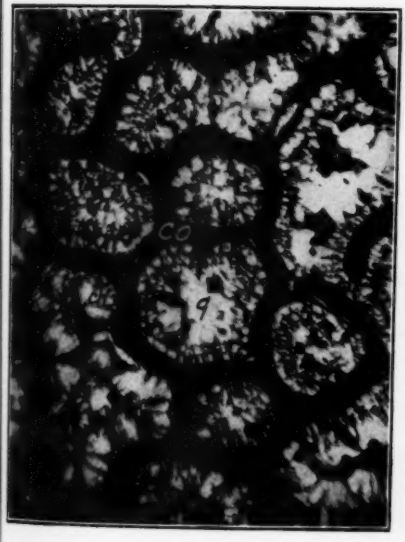

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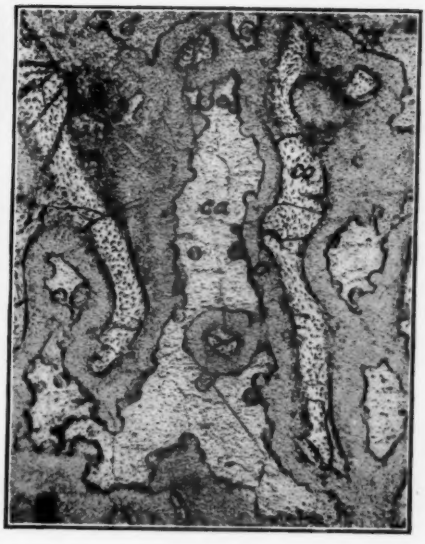

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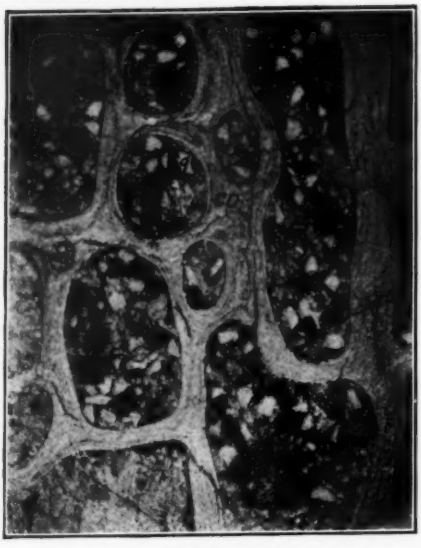
PHOTOMICROGRAPHS OF FOSSIL BONES



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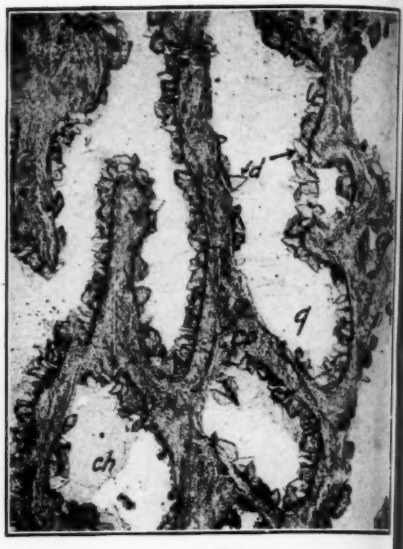

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PHOTOMICROGRAPHS OF FOSSIL BONES

PLATE 28.—*Photomicrographs of Fossil Bones*

(cò = collophane; ca = calcite; q = quartz; ch = chalcedony; d = dolomite; da = dahllite)

FIGURE 1.—Section of cancellated bone from the Pliocene of Capitola, Santa Cruz County, California, with cavity filling of sand grains. (× 43 diameters.)

FIGURE 2.—Oblique section of cancellated bone from the Miocene of Santa Barbara County, California, showing cavity filling of euhedral dolomite crystals, anhedral quartz, and a little chalcedony. (× 42 diameters.)

FIGURE 3. Section of bone (*Diceratherium*) from the Miocene of Nebraska, showing lacunæ and canaliculi. All collophane. (× 1,500 diameters.)

FIGURE 4.—Section of reptile spine from the Permian of Texas, showing cavities filled with dahllite crystals and calcite. (× 70 diameters.)

PLATE 29.—*Photomicrographs of Fossil Bones*

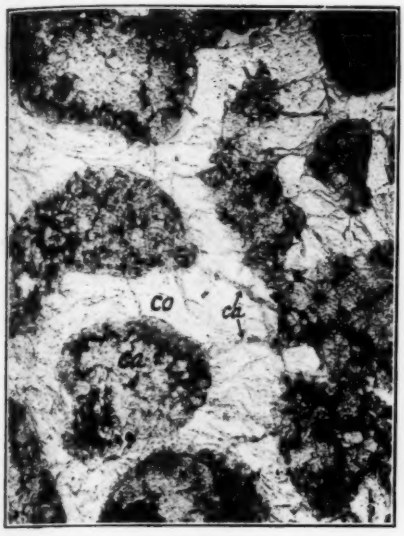
(co = collophane; ca = calcite; ch = chalcedony; q = quartz)

FIGURE 1.—Section of *Naosaurus* bone from the Permian of Texas, showing cavity fillings of calcite and the incipient replacement of collophane by calcite. (× 48 diameters.)

FIGURE 2.—Section of bone from the Miocene of Kern County, California, showing weak double refraction of collophane, cavity fillings of calcite, and the replacement of collophane by films of calcite. Crossed nicols. (× 120 diameters.)

FIGURE 3.—Section of solid bone from the Pleistocene of Samwell Cave, Shasta County, California, showing the extensive replacement of collophane by calcite. Several Haversian systems may be noted. See especially upper right corner. Crossed nicols. (× 51 diameters.)

FIGURE 4.—Section of brecciated bone fragments cemented by chalcedony and with the collophane replaced in part by quartz. Locality near Stanford University, California. (× 89 diameters.)



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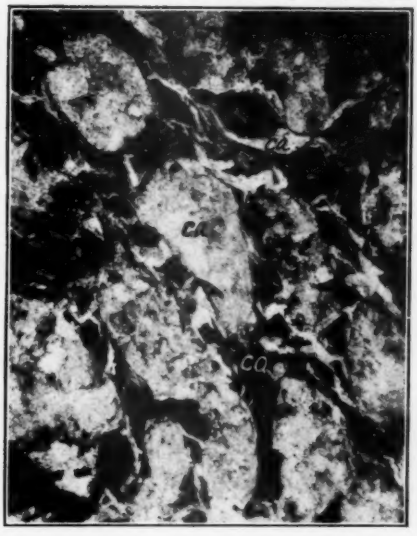

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PHOTOMICROGRAPHS OF FOSSIL BONES

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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FISSILITY OF SHALE AND ITS RELATIONS TO PETROLEUM[1]

BY J. VOLNEY LEWIS

(*Presented before the Society December 29, 1922*)

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[1] Manuscript received by the Secretary of the Society June 12, 1924.

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Introduction

The purpose of this paper is to present a discussion of the nature and origin of shaly structure and its relations to petroleum, together with brief reference to such observational and experimental data as seem pertinent to these problems.

In view of the paucity of knowledge and the importance of this structure from both scientific and practical points of view, the necessity for more extended, and particularly for more critical, field observations and for experimentation under more rigid control, is strongly urged. In the meantime, however, certain tentative conclusions seem to be warranted, and these are set forth here in the hope that they may elicit discussion and thus aid in mapping out the most profitable lines of research.

Nature of Clay

Definition

Clay, which may tentatively be regarded as the chief antecedent of shale, has been defined[2] as:

"A natural substance or soft rock which, when finely ground and mixed with water, forms a pasty, moldable mass that preserves its shape when air-dried; the particles soften and coalesce on being highly heated and form a stony mass upon cooling. Clays differ greatly mineralogically and chemically and consequently in their physical properties. Most of them contain many impurities, but ordinarily their base is hydrous aluminum silicate."

Following the usage of the Bureau of Soils, the term clay has also been widely applied to those fine particles of soil and sediment that measure below .005 millimeters in diameter, without regard to mineral or chemical constitution. It is generally assumed, however, that such materials contain a large proportion of hydrous aluminum silicates, including, perhaps, a wide range of crystalline and amorphous substances. Thus Leith and Mead[3] say:

"Clays represent the fine-grained products of rock decay and disintegration, which have been separated from the coarser-grained materials by the sorting

[2] A. H. Fay: U. S. Bur. Mines Bull. 95, 1920, p. 159.
[3] Metamorphic Geology, 1915, p. 101.

which accompanies erosion, transportation, and deposition. They also include certain substances deposited from solution."

Mechanically the clays grade into the coarser silts and sands, and many shales have been derived from silt, silty clay, sandy clay, and the more heterogeneous mixtures that may be termed mud.

Chemically the average clay and shale are more closely related to the marine clays ("green mud," "blue mud," and "red clay") than to river silts. In content of silica, alumina, and the alkalies, the silts of the Mississippi delta and the lower Hudson River channel are intermediate between average shale and average sandstone.[4] Hence it may be inferred that many shales were originally deposited as clays in open water at some distance from the shore.

MINERAL CONSTITUENTS

Leith and Mead[5] enumerate among the fine-grained products of rock decomposition:

. . . "the clay minerals of the kaolin group, hydrous iron oxides, such as limonite, and fine-grained hydrous aluminum silicates of ferrous iron and magnesia of the chlorite type. Sericite is known to develop from feldspars during katamorphism, and so far as this mineral escapes further alteration to kaolin it may be contributed to the clays and muds. In the clays also an impure white mica, sericite or muscovite, may develop secondarily."

The mineral constitution of the average sedimentary clay, silt, and mud from which shales have been formed may be approximated from the composition of average shale[6] by recalculating and substituting 7.67 per cent combined water (the average of 105 soils and clays) for the 3.68 per cent found in the shales. The results are given in the following table:

Mineral Composition of average Clay calculated from composite Analysis of Shale

Kaolins and hydromicas	43.9
Quartz	31.3
Feldspars	12.3
Calcite	5.4
Limonite	4.2
Gypsum	1.3

[4] F. W. Clarke: Data of geochemistry, 1920, pp. 29, 501, 510.
S. D. V. Burr: Tunneling under the Hudson River. New York, 1885, p. 49.
Several unpublished analyses of the Hudson River silt have been supplied through the courtesy of Mr. Clifford M. Holland, chief engineer of the Interstate Bridge and Tunnel Commission, and Mr. J. Vipond Davies.

[5] Op. cit., p. 101.

[6] U. S. Geol. Survey Bull. 228, 1904, p. 20.

Rutile	.6
Apatite	.3
Carbon	.7
	100.0

It is evident that quartz is a prominent constituent and perhaps generally the most abundant mineral, since it is exceeded only by the aggregate of the kaolins and hydromicas. The more hydrous kaolins, such as newtonite, and colloidal substances like halloysite and allophane must be abundant in many clay strata. On the basis of Hutchings' researches (more fully cited on another page), small amounts of ferrous iron and magnesia have been assigned to the hydromicas. In the clays these substances seem to be present generally in isomorphous mixture and rarely as individualized chlorites and vermiculites.

Besides recognizable kaolinite, and not uncommonly in greater abundance, are hydromicas, such as leverrierite. These minerals may be regarded as either hydrous micas or potassic kaolins, since they are intermediate in both chemical composition and optical properties and are similar in crystallization to both the micas and the kaolins. These close relationships suggest an isomorphous mica-kaolin group of minerals. The suggestion is further strengthened by the variable proportions of water, silica, and the alkalies in the micas; by the readiness with which the micas change into hydromicas and kaolins; and by the marked affinity of the kaolins for the alkalies, particularly potassium. This affinity is more rationally attributed to the replacement of hydrogen in the kaolins, thus converting them into hydromicas, than to the presence of hypothetical zeolites in soils and clays. Under weathering conditions the zeolites are short-lived minerals, and it is difficult to imagine their persistence, much less their origin, in the soils.

Some of the possible members of such a mica-kaolin group may be represented by the following empirical formulæ:

Newtonite (?)	$H_3(OH)_2AlSiO_4$
Kaolinite	$H_2(OH)Al_2(SiO_4)_2$
Hydhomicas	$\begin{cases} (H,K)_2(OH)Al_2(SiO_4)_2 \\ (H,K)_3Al_3(SiO_4)_3 \end{cases}$
Sericite	$(K,H)_3Al_3(SiO_4)_3$

Similarly, the ferromagnesian hydromicas are closely related to vermiculities, chlorites, phlogopite, and biotite; and all of these are also doubtless members of the mica-kaolin group.

Galpin[7] found crystalline intergrowths of kaolinite, hydromicas, and

[7] S. L. Galpin: Studies of flint clays and their associates. Trans. Am. Cer. Soc., vol. 14, 1912, pp. 301-346.

muscovite (sericite), apparently isomorphous, in many flint, semi-flint, and plastic clays from Ohio, Pennsylvania, Maryland, and Kentucky. The optical properties showed every grade of variation between the two extremes. Many of the samples contained 60 to 70 per cent micas and hydromicas, and in some there was no recognizable kaolinite. These last had lower proportions of combined water. Some areas in the thin sections were more distinctly crystalline than other areas of the same sections, "indicating varying stages of recrystallization," with the platy grains thoroughly intergrown and interlocked. Some sections showed clean-cut rims of hydromica upon muscovite, indicating the isomorphous growth of the crystals with molecules of lower alkali content. Galpin concludes that the microscopic evidence points to the probability of an isomorphous mica-kaolin group.

Somers[8] found abundant scales, plates, vermicular crystals, and fan-shaped aggregates of both kaolinite and hydromica in clays of residual and sedimentary origin from various parts of the United States. Somers supposed the hydromica to have been derived from feldspars and to represent a stage of weathering toward kaolinite as a final product. His estimates of the relative proportions of kaolinite and hydromica may be tabulated as follows:

Kaolinite and Hydromica in Clays

	Residual	Sedimentary	Total
No hydromica observed	2	4	6
Kaolinite more abundant than hydromica	20	21	41
Kaolinite and hydromica about equal	11	21	32
Hydromica more abundant than kaolinite	4	22	26
Total number of clays	37	68	105

It is noteworthy that 99 of the 105 clays contain hydromica, and that this mineral was found in amounts equal to or greater than the kaolinite in 58 of them (15 of the residual and 43 of the sedimentary). Quartz was found in considerable abundance in the residual clays, but in much smaller proportions in the sedimentary ones.[9] Needles and grains of rutile were observed in great numbers in nearly every sample, tourmaline was frequently seen, zircon and titanite were common, and epidote was occasionally found. Many of the clays also contained much amorphous-looking material, which was supposed to be chiefly kaolin.

These results are in close agreement with the researches of various

[8] R. E. Somers: Microscopic examination of clays. Jour. Wash. Acad. Sci., vol. 9, 1919, pp. 113-126.

[9] In this respect the selected commercial clays do not coincide with the average shale.

earlier observers. Thus, in 1867, Johnson and Blake[10] found that clays consist for the most part of minute transparent plates, either separate or in fan-shaped aggregates and vermicular prismatic crystals with perfect basal cleavage. This material was assumed to be chiefly kaolinite. Similar observations were made on New Jersey clays by Cook[11] in 1878 and on Missouri clays by Haworth[12] in 1896; also, in 1890 to 1896, Hutchings[13] published a series of papers in which he sets forth the results of extended research on the soft clays, shales, and clayey sandstones of the Coal Measures from various localities in Great Britain. The rocks are folded and some of the clays are faulted and puckered, but both clays and shales are still soft. Hutchings found the clayey "paste," or matrix, of the clayey sandstones and micaceous beds and also the chief substance of the clays themselves to consist largely of minute flaky hydromica and granular amorphous "kaolin" full of rutile needles. The mica plates lie parallel to the bedding, and Hutchings concluded that they were formed in the clays and shales from powdered feldspars and from colloidal kaolin with adsorbed potash. Unlike the original clastic flakes, this secondary mica contains minute needles of rutile. He also concluded that the decay of feldspars, both in the original rock and as powder in the sediments, probably yields more hydromica than kaolin.

Besides the clastic constituents, many clays and muds contain numerous remains of organisms, such as foraminifera, sponges, and diatoms, and also colloidal materials of many kinds, including alumina, silica, ferric hydroxide, kaolin-like aluminum silicates, and a great variety of organic ("humic") substances. In sea-water these colloids are flocculated and precipitated through the electrolytic action of the dissolved salts. In fresh water, on the other hand, they remain largely in suspension. Eventually this difference may furnish an additional criterion for distinguishing marine clays, claystones, and shales from those of fresh-water origin.

CONDENSATION OF CLAY

The wide range in the density of clay deposits and the marked difference between clays and shales may be attributed chiefly to the differences in pressure, or weight, to which they have been subjected and the length of time during which the pressure has operated. Freshly deposited clay

[10] S. W. Johnson and J. M. Blake: On kaolinite and pholerite. Am. Jour. Sci. (2), vol. 43, 1867, pp. 351-361.

[11] G. H. Cook: Clay deposits of New Jersey. Geol. Survey of New Jersey, 1878, pp. 280-283.

[12] E. Haworth: Clay deposits. Missouri Geol. Survey, vol. 11, 1896, pp. 95-108.

[13] W. M. Hutchings: Geol. Mag., dec. 3, vol. 7, 1890, pp. 264-273, 316-322; idem, dec. 4, vol. 1, 1894, pp. 36-45; dec. 4, vol. 3, 1896, pp. 309-317, 343-350.

may contain more than 85 per cent of water by volume and have a density, or mass specific gravity, below 1.25. Engineers of the Interstate Bridge and Tunnel Commission have collected samples of semi-liquid mud from the bottom of the Hudson near Canal Street, New York City, which contained by volume 77.15 to 88.40 per cent water; and mud deposited on a crate suspended from Erie Railroad pier number 9, Jersey City, yielded by weight 73.67 per cent water, or by volume 88.18 per cent. Assuming an average mineral density of 2.7, the mass specific gravity of this last material is 1.21.

The density of 86 New Jersey clays[14] ranges from 1.54 to 2.17 and the average is 1.82. Wheeler[15] found that the superficial clays of Missouri, residual and transported, range in density from 1.69 to 2.02 and average 1.90, while the shales range from 2.15 to 2.56 and average about 2.38. The Tertiary clays, which have been subjected to less pressure than the shales, are intermediate in density, ranging from 1.93 to 2.13. Similarly, a washed clay that has settled and been air-dried in shallow tanks, under pressure of only 1 to 2 pounds, has the density of 1.92, while one that has been subjected to the pressure of 100 pounds to the square inch in a filter press has the density of 2.13.

It is difficult to conceive of the mechanism involved in the elimination of water from clay of even moderate density, and its passage in vast quantities through deposits hundreds and even thousands of feet thick seems impossible. It is obvious, however, that this has taken place continually throughout sedimentary history. How and by what course the water escapes is a problem that seems to present great difficulties.

King[16] found that during the settling of water-soaked sediments (soil or fine sand) less than 4 feet deep, the eliminated water in part passed downward into underlying sand and gravel and flowed in considerable quantity out of the upper end of a rubber tube and back into the reservoir, rising 6 inches above the level of the soil and water in it. This principal, as King points out, must have come prominently into play during the process of sedimentation in all geologic ages and particularly where heavy deposits of fine sediments have been laid down over those of coarser texture. The water entering the sands would flow up the depositional slope, even against considerable head—the exact opposite of artesian flow.

King also cites the experiments of Seelheim[17] on the perviousness of clay-water mixtures. Ratios of 5 clay to 3.286 water, by weight, and of

[14] G. H. Cook: Op. cit., pp. 283-286.
[15] H. A. Wheeler: Missouri Geol. Survey, vol. 11, 1896, pp. 90, 91.
[16] F. H. King: Principles and conditions of the movements of ground water. Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 79, 80.
[17] F. Seelheim: Zeitschr. für analyt. Chemie, vol. 19, p. 387.

5 to 1.505 were used. These correspond respectively to 39.7 and 23.1 per cent of water by weight and to 63.0 and 43.9 per cent by volume. The calculated density was 1.59 and 1.90. Calculations on the basis of Seelheim's results show that the clay-water ratio of 5 to 1.329 by weight should be impervious under the conditions of the experiment. This corresponds to the water content of 21 per cent by weight and 40.5 per cent by volume and to the density of 1.95. Doubtless the interstices in many natural clays attain subcapillary dimensions, thus rendering them impervious, at a density about 1.90 to 2.00.

Evidence that seems to bear upon this phase of the problem is found in the persistence of salt water in the Cretaceous and Tertiary sands of the Atlantic Coastal Plain, despite the pressure of an artesian head up to several hundred feet in some regions. Seaward, presumably the sands grade into clays or lens out between beds of clay, and the escape of the brine in this direction has been extremely slow. The open channels lead shoreward, up the depositional slope; hence the salt water slowly diffuses into the meteoric ground water and thus escapes by way of the surface drainage. In places, also, joints and fissures may permit more direct escape through artesian springs.

Where the flooding method has been employed for the recovery of petroleum in the oil fields of New York and Pennsylvania, the water, which enters the sands under pressure, with free escape for the oil through neighboring wells, moves only 50 to 200 feet in a year. The rate varies with the pressure, the porosity and thickness of the sands, and the content and viscosity of the oil.[18] No method has yet been devised for estimating the infinitesimal creep of water, as it is driven against tremendous resistance from the great accumulations of clay. The time required for the condensation of such material is doubtless long, even in the geologic sense.

CONDENSATION IN HUDSON RIVER SILT

Light is thrown on some phases of this question, perhaps, by conditions that have been observed in the fine sediment of the depressed Hudson River channel, through which pass the three pairs of railway tunnels that connect New York and New Jersey and in which the great vehicular tunnels are now being constructed.

A clayey silt of dark slate-gray to greenish-gray color fills the channel to the depth of 300 feet, with local intercalated sand lenses, chiefly below 150 feet, and a gravelly hardpan 10 to 40 feet thick at the bottom. When dry, the silt is readily crumbled in the hand to an impalpable powder,

[18] J. M. Clarke: Seventeenth Rept. Director New York State Museum, 1922, p. 16.

94 to 97 per cent of which passes the screen of 100 meshes to the inch (diameters 0.14 millimeters and smaller) and 83 to 94 per cent passes the 200-mesh screen (0.066 millimeters and less). Under the microscope a large proportion of the material is found to be even smaller than 0.005 millimeters in diameter, and hence to fall into the technical category of clay. The average of 5 chemical analyses,[19] which show but moderate range in composition, is equivalent approximately to the following mineral constitution:

Quartz	41.0
Kaolins and hydromicas	37.0
Hornblende	9.0
Feldspar	5.5
Garnet	2.5
Magnetite	2.0
Calcite	1.5
Rutile	1.0
Gypsum	0.5
	100.0

The free silica ("quartz") includes, besides quartz sand, silt, and flour, many diatoms. One analysis found 2.77 per cent of such colloidal silica. The calcite also includes scattered foraminifera.

When wet, the silt is compact and tenacious like putty and is nearly impervious to both air and water. Mixed with much water, it flows like quicksand and is very difficult to control. At the bottom of the channel the silt ranges in weight from 78 to 80 pounds per cubic foot, corresponding to density, or mass specific gravity, from 1.25 to 1.28. Twenty to 40 feet deeper the range is 103.5 to 113.5 pounds per cubic foot (specific gravity, 1.65 to 1.81), the average increase being about 6 pounds per cubic foot (0.1 in specific gravity) for every 10 feet in depth. This increase in density with depth interposes a greater resistance at the bottom of the shields than at the top, and this doubtless accounts for their pronounced tendency to "dive," which made it difficult at first to drive them on the desired gradient. At the depth of 50 feet on the shore the silt is firmer and is said to resemble the stiff London clay. Even the denser sediment still retains 55 to 65 per cent of water by volume.[20]

[19] S. D. V. Burr: Op. cit., p. 49, gives an early analysis by Professor Leeds. For access to unpublished analysis the writer is indebted to the courtesy of Mr. J. Vipond Davies and Mr. Clifford M. Holland.

[20] S. D. V. Burr: Tunneling under the Hudson River. New York, 1885, pp. 50-52. Also B. H. M. Hewett and S. Johannesson: Shield and compressed air tunneling. New York, 1922, pp. 288, 295.

C. W. Raymond: Proposed supports and foundations. Pennsylvania Railroad Co., New York Tunnel Extension, 1911, pp. 40, 52.

The silt was sufficiently firm to permit the construction of 1,540 feet of the first tunnel (by Haskins, 1874-1880) by hand excavation without the protection of a shield. In all later work shields were used, and as these were driven forward by hydraulic jacks exerting pressure of 3 to 8 tons per square foot of cross-section, the firm silt became semi-fluid. Whenever the air pressure was allowed to drop 10 to 15 pounds below the hydrostatic pressure this liquefied silt would flow into the tunnels at a rate from 10 to 15 gallons per minute through the grouting holes, 1½ inches in diameter, as soon as the plugs were removed.

In the construction of the Hudson and Manhattan tubes only 5 per cent of the material was taken into the shields. Much of the construction was done "shoving blind," with all doors closed. In the larger tunnels of the Pennsylvania Railroad it was found necessary to admit an average of 33 per cent of the silt in order to guide the shields along the desired course,[21] and approximately the same proportion holds for the vehicular tunnels now under construction.

During construction the Pennsylvania tunnels subsided the average amount of 0.34 foot (4.08 inches, or 10.36 centimeters), and after completion they settled an additional 1½ inches (3.81 centimeters) in 7 years.[22] A similar sinking of 2 to 4½ inches was observed in the Hudson and Manhattan tunnels[23] and doubtless occurred in all tunnels of the district wherever they are imbedded in soft sediment. Since with maximum live load the tunnels are lighter than the saturated silt, and since perceptible movement stopped with the gradual sealing of the leaks, this settling may be regarded as an approximate measure of the condensation that took place in the enveloping sediment while there was free escape for an appreciable amount of water.

INDURATION OF CLAY

Van Hise[24] has emphasized the importance of cohesion, or "welding," in the consolidation of the mud and clay rocks. He estimates that the number of points of contact established between the particles as the water is squeezed out ranges from 60,000 to 174,000 times as great in these rocks as in beach sands or such a sandstone as the Saint Peter.

However, it should be added that under the same conditions cementation may also be accentuated. Although there is little or no infiltration

[21] Hewett and Johannesson: Op. cit., pp. 290, 293.

[22] G. H. Gilbert, L. I. Wightman, and W. L. Saunders: Subways and tunnels of New York, 1912, p. 89.

[23] C. W. Raymond: Op. cit., p. 10.

[24] C. R. Van Hise: A treatise on metamorphism. U. S. Geol. Survey Mon. 47, 1904, pp. 892-894.

of mineral solutions, the vast amount of interstitial water in clays affords abundant opportunity for solution and redeposition, and this supply is augmented by additional water from the dehydration of constituent minerals and colloids. Furthermore, extensive cementation may result from the condensation of the colloids, both at the points of contact between particles and through filling of the interstices generally. The process may also be aided by the reduction of ferric oxide and hydroxide into ferrous carbonate and of sulphates into sulphides and the crystallization of these products. On the other hand, where solution is more active than deposition in the early watery stages, much dissolved matter may be lost through the elimination of water during condensation. Under such conditions welding might be practically the only means of consolidation.

Induration of clayey rocks, therefore, probably differs from that of other sediments chiefly in (1) the vast number of points and surfaces of contact between the minute constituents, (2) the practical exclusion of extraneous mineral solutions, (3) the influence of the great proportion of interstitial water, and (4) the abundance of highly hydrous minerals and colloids that are readily dehydrated, wholly or in part, under moderate increase of pressure and temperature.

Meaning of Shale and Shaly

Vague and confusing usage

The importance of shaly structure is obvious from the great dominance of shale among the sedimentary rocks; yet probably no other structure is so vaguely defined and comprehended and withal so generally taken for granted. Few authors of geologic textbooks and manuals have attempted to define it, and in several important works of this type there is no suggestion of its meaning. Among available definitions that of Thiessen[25] probably represents the prevailing contemporary usage:

> "A shale is generally defined as a rock formed by the consolidation of clay, mud, or silt, having a finely stratified, laminated, or fissile structure."

La Forge[26] is more specific as to structure:

> "*Shale.*—A fine-grained, fissile, argillaceous, sedimentary rock characterized by rather fragile and uneven laminæ and commonly a somewhat splintery fracture."

The Century and Standard dictionaries specify a fissile structure, while

[25] R. Thiessen: Econ. Geol., vol. 16, 1921, p. 289.
[26] U. S. Bur. Mines Bull. 95, 1920, p. 606.

Webster's New International calls for "a finely stratified or laminated structure."

The parallel lamination of many so-called shales, shaly limestones, sandy shales, and the like, which consist of alternate layers of sorted materials, is simply bedding or stratification on a small scale. At the opposite extreme the massive clay and mud rocks with no trace of shelly structure are also commonly called shale. Obviously the massive and laminated types are fundamentally different in origin and history from fissile shale and are therefore entitled to distinctive names.

Massive clay and mud rocks may appropriately be called *claystone* and *mudstone*, and happily these terms are coming into more common use. The older erroneous use of claystone as the name of a concretion found in clay or shale should not be permitted to stand in the way of this reform. It is not so easy to suggest acceptable names for rocks of alternate thin layers of different materials. They may be described as interfoliate or interlaminate sand and clay, sandstone and shale, etcetera, according to the character of the laminæ; but such terms are cumbersome as names, and a more convenient terminology is desirable. Among the terms in current use, perhaps *paper shale* will serve as well as any. It may be objected, however, that this name implies an analogy that does not exist between such laminate structure and the fissility of shale.

DEFINITION OF SHALE

As here used and advocated, shale, like slate, schist, and gneiss, is a structural term. It implies no particular composition except so far as certain materials of fine texture lend themselves to the development of the characteristic structure. This structure, or fissility, may be defined as the capacity of clayey strata for splitting into somewhat uneven flakes, thin chips, and wedgelike fragments approximately parallel to the bedding. It also commonly shows a tendency to splintery fracture. Fissility is typically developed in most of the clay rocks of finer texture and in various unsorted mixtures, such as silty clay, sandy clay, and mud,[27] and is commonly most conspicuous on weathered surfaces.

MINERAL CONSTITUENTS OF SHALE

The mineral changes involved in the transformation of clay into shale are chiefly those associated with dehydration. The average amount of

[27] Compare C. K. Wentworth: A scale of grade and class terms for clastic sediments. Jour. Geol., vol. 30, 1922, pp. 377-392. Dr. Wentworth makes no provision in his admirable classification for such crude mixtures as contain more than 10 per cent of clay, silt, and sand. For such as these the term *mud* may be conveniently retained.

combined water in 105 analyses of soils and clays from various sources is 7.67 per cent. In the composite analysis of 78 American shales[28] it is 3.68 per cent, and in 29 American and foreign roofing slates[29] it is 3.40 per cent. Hence the clays, on becoming shale, typically lose more than half their combined water, whereas in the transformation of shale into slate there is little or no further loss. Loss of plasticity in shale, only partially restored by grinding in water, also points to chemical change. With this greatly reduced amount of water, much of the alumina must now be assigned to other minerals than those of the kaolin group.

Since both the range and the average water content are nearly the same in shales and slates, the abundant hydromicas and chloritic minerals of shale require only mechanical rearrangement and recrystallization when the shale becomes slate. Hutchings[30] concluded that in the fine-grained sediments, exposed long enough to the necessary conditions,

> . . . "an almost complete regeneration of the 'paste' to mica can and does take place, and that this regenerated material under intenser dynamometamorphic action is converted into some of the forms of micaceous slates known to us. The mica so formed is probably what in its more advanced stages of development is often known as sericite."

It is evident that much of the hydromica in shale has already attained, or very nearly attained, the stage of sericite, otherwise a pronounced dehydration would mark the further transition to slate.

Basing his estimates on the chemical and microscopic analyses of the principal varieties of slate from the French Ardennes, Renard computes the following range of mineral constituents:[31] Sericite, 38-40 per cent; chlorite, 6-18; quartz, 31-45; hematite, 3-6; rutile, 1-1½. Similarly, the composite analysis[32] of 78 shales may be computed into the approximate mineral constitution shown in the following table:

Mineral Constitution of average Shale computed from composite Analysis[33]

	A	B
Quartz	33.6	31.91
Sericite	25.1	18.40

[28] U. S. Geol. Survey Bull. 228, 1904, pp. 20, 21.
[29] U. S. Geol. Survey Bull. 586, 1914, pp. 50, 51.
[30] W. M. Hutchings: Geol. Mag., dec. 3, vol. 7, 1890, p. 317.
[31] Quoted by T. N. Dale: U. S. Geol. Survey Bull. 586, 1914, p. 19.
[32] U. S. Geol. Survey Bull. 228, 1904, p. 20.
[33] A, by the author; B, by Leith and Mead. Metamorphic Geology, 1915, p. 76. Column A was computed as follows: Gypsum and apatite on the basis of P_2O_5 and SO_3; the remaining CaO and part of MgO assigned to CO_2; rest of MgO with FeO to chlorite (clinochlore); Fe_2O_3 to limonite; remaining Al_2O_3, Na_2O, K_2O, and H_2O were distributed by means of simultaneous equations to sericite, kaolinite, and albite; surplus SiO_2 calculated as quartz.

	A	B
Chlorite	10.1	6.40
K, Na feldspar	13.0	17.60
Limonite	4.5	4.75
Kaolinite	4.7	10.00
Calcite	5.8	7.90
Gypsum	1.4	1.17
Rutile	.7	.66
Apatite	.3	.40
Carbon	.8	.81
	100.0	100.00

Hutchings finds much iron and magnesium in some of the earlier hydromicas in the clays. Upon partial dehydration in shale and slate these mixed molecules become differentiated into sericite, chlorite, and biotite. Biotite seems to originate chiefly under dynamometamorphic conditions. Rutile needles, already abundant in some soft clays, may develop further in shale and slate out of the remaining colloids.

Fissility of Shale

Nature and origin

Statements concerning the origin of shaly structure in textbooks and manuals of geology show the widest difference of opinion, and in practice there is even greater latitude and confusion. Thus Geikie[34] describes shale as "capable of being split along the lines of deposit into thin leaves." Pirsson[35] states specifically that "this parting is parallel to the bedding and is the result of natural stratification." On the other hand, Dana[36] regards it as "due more or less to the pressure of overlying material," and Graubau[37] is positive that "the structure is a secondarily derived one, due to vertical pressure and the character of the rock." That such widely divergent and even contradictory views have led to no controversy nor even casual comment attests the general indifference concerning the structure.

For reasons set forth in the following pages, the fissility of shale is believed to be clearly of secondary origin and to reflect in some degree the conditions to which these rocks have been subjected—that is, the structure of shale, like that of slate, schist, and gneiss, is regarded as an acquired character which may be interpreted as a partial record of the rock's history.

[34] A. Geikie: Textbook of Geology, 4th ed., vol. 1, 1903, p. 169.
[35] L. V. Pirsson: Physical Geology, 2d ed., 1920, p. 283.
[36] J. D. Dana: Manual of Geology, 4th ed., 1895, p. 92.
[37] A. W. Grabau: Principles of Stratigraphy, 1918, p. 785.

Among the processes concerned in the development of fissility in shale, the chief are conceived to be gravitational compression and plastic flow. Both of these are doubtless generally active in unconsolidated sediments and both are subject to modification by several other processes, most of which are also primarily of gravitational origin.

GRAVITATIONAL COMPRESSION

The finer the subdivision of a solid the smaller the proportion of it required to convert a liquid into a plastic medium; and, conversely, the finest sediment entraps the greatest proportion of interstitial water and forms semi-liquid and plastic beds of the highest mobility, as commonly observed in freshly deposited clay. With the lapse of time and the increasing burden of overlying sediments, gravitational compression is doubtless the chief factor in the slow condensation of these deposits, and the process consists essentially in the squeezing out of the entrapped water. This process is aided in great measure by long-continued differential stresses and by incessant infinitesimal kneading and jigging movements among the particles. Direct gravitational settling of the particles into contact with one another, as commonly occurs in sand and gravel, probably never takes place on any important scale in clays.

In the compacting of the finest sediments, there is enormous loss of volume. For example, a watery clay of apparent specific gravity 1.3 (81 pounds per cubic foot) is converted into a shale or claystone of density 2.5 only after the loss of 80 per cent in volume and the consequent reduction of the stratum to one-fifth its former thickness. Probably the condensation in clays and muds is seldom less than 60 per cent. The average commercial clay with the density 1.85 and 32 per cent of voids is already half condensed. The greater part of the loss in volume is due to the elimination of interstitial water; but there is also shrinkage because of progressive chemical dehydration, and heavy losses may result from the conversion of organic matter into liquid and gaseous hydrocarbons and their gradual elimination. In contrast, the loss of volume in sand probably seldom exceeds 20 per cent.

The maximum and minimum percentages of voids in an aggregate of uniform spheres in contact are respectively 47.64 in the "square-packed" structure and 25.95 in "tetrahedral packing." The maximum value is approximated in some rounded and well sorted sands and the minimum in many sandstones, but wholly different conditions are found in the clays. Entrapped water may constitute more than 85 per cent of the volume in such sediments when freshly deposited. The loosely flocculated colloids contain but a small proportion of solid matter and few of the

clastic particles can be in actual contact. On the other hand, the firmer clay rocks have been condensed to less than one-half the minimum porosity for uniform spherical aggregates. This density may be attributed in part to mixed sizes of particles and to angular and irregular shapes, but in great part it is doubtless due to recrystallization, to the molding of soft constituents, and to the filling of interstices by colloids and their dehydration products.

Watery oozes may be regarded as sediment still in process of deposition, but no sharp distinction can be established between clayey water and watery clay, since these mixtures grade imperceptibly from mobile liquid to stone of maximum density.

PLASTIC FLOW

In a granular aggregate, such as sand and silt, plastic flowage is accomplished by the sliding of the solid particles over one another. If the granules are approximately equidimensional, they assume a rotating motion, but with different speeds at different levels; hence there is constant friction and interference among them until they attain the square-packed structure, which converts the plastic mass into a solid. Differential stresses may eventually condense this to tetrahedral packing, the densest mechanical structure possible with particles of uniform size. On the other hand, the bed may become indurated at an earlier stage, through cohesion or cementation, while much space is still occupied by interstitial water. This will result in a stone of higher porosity unless the voids are partly filled by precipitated mineral matter.

In contrast with the sands, clays of high plasticity carry a large excess of water, besides flocculent and gelatinous colloids, and hence they flow the more readily; but, as previously noted, such materials eventually condense into stone of higher density than is possible through the mechanical packing of granular sediments.

With increasing load there is a growing tendency for all sediments to creep down the depositional slope, and through the aid of various accessory processes actual movement may often result, particularly in the watery colloidal clays. While deposition continues, every gradation may be found from colloidal suspension and liquid sludge to compact clay below and, with sufficient depth, to dense shale or claystone. Through long transition periods such deposits doubtless remain sufficiently mobile to yield to slight differential pressure, and flow is doubtless everywhere more active in these sensitive materials than is soil-creep on land slopes of the same gradient. In fresh-water deposits, however, generally less plasticity, and consequently less movement, may be expected than in those of marine origin, because of the paucity of colloids.

The magnitude of the thrust that tends to produce flow of sediments down the depositional slope varies directly as the tangent of the angle below the horizon and the weight of the overlying load, and may be expressed by the equation $T = w. \tan a.$ Thus, on the gradient of 30 feet to the mile (0° 19.5′, or 0.57 per cent), this lateral thrust is 11.4 pounds for every ton of overlying material; for the slope of 1 degree it is 35 pounds, and for 3 degrees 104.8 pounds per ton. In the last example the thrust down the slope is equal to 5¼ per cent of the superincumbent load.

In the deeper strata generally it may be assumed that the gradual elimination of the water and the corresponding rise in density tend to lower the plasticity of the clays and increase their resistance to flow. This tendency must be offset in some degree by the greater overburden and the rise in temperature with increased depth. Furthermore, in sediments at all depths, minute vibratory and kneading movements of the particles also tend to maintain a certain degree of mobility. Plastic flow will take place wherever and whenever the combined action of these movements and the differential stresses overcome cohesion and frictional resistance.

Hence, since both compression and plastic flow involve movements of the individual particles, each process tends to facilitate the operation of the other. Moreover, the clay rocks retain to a marked degree the capacity to flow, not only during the earlier period of condensation, but also as shale, slate, and schist, to the ultimate stages of metamorphism.

Accessory Processes

Kneading and jigging movements

Various oscillatory and vibratory movements contribute to the processes of gravitational compression and plastic flow. Chief among these are tides, waves, earthquakes, seasonal oscillations, and variations in atmospheric pressure. Various combinations of these may give rise to, and in turn be accentuated by, offshore slumping, or mass movements of sediments. Vibrations and oscillations tend to decohere the particles and preserve their individual freedom of motion in much the same manner, in the early watery stages, as the action of the jig upon particles of crushed ore and rock.[38] In the denser clays and in firm sediments generally the movements may be compared to kneading.

[38] David White employs this felicitous comparison in discussing the effect of diastrophic movements upon sediments; but the process as he pictures it seems wholly applicable here: "In some respects the effects of diastrophic stresses in compressible sedimentary strata may be likened to a jigging of rock particles and mineral grains, in which process existing capillaries may become unstable and disrupted, pore spaces reorganized as to number, form, and size, and friction repeatedly overcome." Genetic problems affecting search for new oil regions. Mining and Metallurgy, no. 158, sec. 21, February, 1920, p. 14; also Trans. Am. Inst. Min. and Met. Engrs., vol. 65, 1921, p. 189.

TIDES

Except about the shores of the greater bodies of water, the solid earth is essentially free from tides. The slight elastic yielding of the lithosphere to tidal stresses is accepted as proof of high rigidity. Adjustments within the zone of flow, however, may be effectively aided by these daily stresses, and it cannot be doubted that soft sediments everywhere are continually kneaded by them.

Sensitive seismographs record a distinct tilting of the continental borders with the flow and ebb of the tide, and this regular loading and unloading must also aid compression and plastic movements. Extraordinary effects must result from those occasional climaxes due to the conjunction of spring tides with onshore storm winds and heavy rainfall. A 5-foot tide, for example, places an additional load of more than 300 pounds upon every square foot of surface. Oscillations of water level in wells near the shore and the fluctuating flow of some artesian wells and oil wells are doubtless correctly attributed to this cause.

The clayey silt in the channel of the Hudson at New York City has been found to sway continually with the tides at depths of 20 to 30 feet below the bottom of the channel. Records of the Pennsylvania Railroad tunnels for seven years after their completion showed an average vertical displacement of about one-eighth of an inch (3 millimeters) under a 4-foot tide, the tunnels going down under the flow and gradually rising with the ebb. At high tide, also, the silt was found to be somewhat denser and to contain less water than at low tide. The increased pressure drives out some of the excess water and brings the particles nearer together. The water escapes with difficulty; hence there is little compression in the 6 hours of tide. The rebound with the ebb resembles the behavior of elastic material and is undoubtedly attributable to the thickening of the water films between the particles. Doubtless appreciable movement takes place in such materials at much greater depths. Even the stiff London clay is said to show small oscillations under a tidal range of 20 feet.[39]

The magnitude of tidal influences in sedimentation cannot now be estimated because of the lack of fundamental data; but, since tidal kneading is universal and continuous in operation, it seems clear that it must rank with geologic processes of importance.

[39] Hewett and Johannesson: Op. cit., p. 295. Gilbert, Wightman, and Saunders: Op. cit., p. 347.

VARIATIONS IN ATMOSPHERIC PRESSURE

Barometric variations of 150 pounds per square foot are frequent and rapid, and in extreme cases they are nearly double this amount. Strong winds accompany these variations, and by driving the water upon the land, or the reverse, they greatly extend the range between maximum and minimum pressures along the shore. Thus effects are obtained that are equivalent to the sudden addition or removal of many feet of overlying sediments. In cooperation with waves and tides, these variations must often contribute to active compression and flowage in the underlying muds and clays.

Vibrations of an average amplitude about 1 micron are almost continuously recorded by delicate seismographs. In winter the amplitude is more than double this amount and less than half in summer. The origin of these vibrations is not yet understood. They may be connected with meteorologic conditions, perhaps cyclonic disturbances.

WAVES

Sand is sometimes reported to have been thrown upon the decks of ships by breaking waves in water 60 to 75 feet deep. Even gravel is moved on the bottom to the depth of 150 feet in open sea, and ripple-marks have been found on sand as deep as 600 feet. Oozes and soft clays must be affected in water of considerably greater depth, and in shallow water it can scarcely be doubted that such sediments are swayed by wave vibrations far below the bottom.[40]

The impact of waves against the shore sets up vibrations that are recorded by sensitive seismographs, and such records may be superposed on those of earthquakes. All such movements tend to reduce friction and cohesion among the particles, and thus they cooperate with the lubricating agents in promoting plastic flow and compression.

EARTHQUAKES

Loose materials are profoundly affected by earthquakes along those great reaches of shoreline that are specially subject to these disturbances. No region is entirely free from local tremors, and every year about 60 great convulsions shake the whole earth. Hence these vibrations, like the slower oscillations of the tides, are universal in their operations, and because of their high frequency they are the more effective in overcoming friction and cohesion.

[40] D. W. Johnson: Shore processes and shoreline development. New York, 1919, pp 76-83. Many examples of wave agitation in deep water are cited.

Besides their direct influence, earthquakes and other vibratory disturbances doubtless often condition the operation of gravitational processes when these alone fall short of the requisite "yield pressure" to overcome cohesion and frictional resistance.

SEASONAL MOVEMENTS

Only slight oscillations on land and beneath shallow water may be attributed directly to seasonal changes of temperature, since these are limited to very shallow depths. More pronounced effects must result, however, from variations in the density of water. These arise in part from temperature changes, but in the sea the principal fluctuations are due to seasonal or irregular variations in rainfall and flood-waters from the land.

Records of the Pennsylvania Railroad tunnels, through the Hudson River silt at New York City, show an average seasonal displacement of five-sixteenths of an inch (7.94 millimeters), the tunnels rising in summer and sinking in winter. No satisfactory explanation of this movement has yet been found. The writer ventures to suggest that it may result from seasonal variations in the density of the water. Low temperatures (below the annual average) prevail from November to April, inclusive, and high salinity from July to January.[41] The dominant influence of salinity gives water of high density from August to January, inclusive, with the average weight of 0.6 pound per cubic foot in excess of that from February to July, and the difference of 1 pound between the maximum and minimum monthly averages. Hence the compressive effect of the denser water should culminate in January. The movement is due to the actual elimination of water from the silt, a portion of which returns, however, under the lower pressure of summer. The effective pressure is an oscillating one, owing to the regular rise and fall of the tides and the irregular variations in atmospheric pressure, in rainfall and flood-waters, and in the driving effects of onshore and offshore winds in raising and lowering the water level.

SLUMPING

Mass movements comparable to landslides sometimes take place in soft sediments under water on slopes of very low gradient. Such slumping has doubtless been active at some time along most shores, where it is a common cause of the sinking of land. Generally the movement is due directly to the plastic flow of clay. Slips of this nature sometimes

[41] H. De B. Parsons: Tidal phenomena in the harbor of New York. Trans. Am. Soc. Civ. Eng., 1913, p. 1979.

transfer great quantities of material into deeper water, thus building up the bottom offshore and reducing the depositional slope. In this manner they tend to prevent the recurrence of such movements in the same locality.

Once under way, slumping on a large scale may appreciably accentuate the vibrations that gave it birth, and thus the effect may temporarily become cumulative.

Earthquakes have sometimes been ascribed to slumping of sediments, but it may be questioned whether cause and effect have not generally been confused in such cases. Naturally the gentle creep of plastic beds will sometimes be quickened under the influence of high-frequency earth tremors, the kneading action of spring tides, and the several jigging and vibrating processes that have been enumerated. Whenever the disturbance breaks down cohesion and the packing structure, even firm beds will flow like quicksand, with little change in density. This principle was continuously demonstrated during the construction of the tunnels by the shield method through the clayey silts of the Hudson River channel at New York City. The high proportion of intersitital water and the dominant content of quartz silt point to the square-packed structure as the probable cause of the remarkable firmness of these sediments. This structure was broken down along the lines of operation by the tremendous thrust of the shields, as they burrowed through the silt like giant moles.

Development of Fissility

Suggestions of secondary origin

As previously noted, J. D. Dana, A. W. Grabau, and others have suggested, incidentally and somewhat vaguely, that shaly structure may be due in a measure to the weight of overlying strata and to the nature of the rock materials. Grenville A. J. Cole[42] specifically attributes the structure to the rotation of original flaky constituents. No attempt is made, however, to formulate a theory or to analyze the operation of the processes involved.

Effects of compression and flowage

Owing to the readiness with which clay and shale yield under differential pressure, the "swelling" of these materials due to plastic flow is a common source of trouble in both mining and well-drilling. At greater depths mica schist also behaves in a similar manner.

[42] G. A. J. Cole: Rocks and their origins. The Cambridge Manuals of Science and Literature. Cambridge, 1922, pp. 83, 84.

Pressure flattens the soft particles and flocculent aggregates of clay into tabular and scaly forms and, during condensation of the sediment and elimination of interstitial water, turns them, together with the minute flakes of the hydromicas and the crystalline kaolins, approximately into parallelism with the bedding. Flowage tends to elongate the flattened particles and also to rotate the longest axes into the direction of movement.

Many processes contribute to the kneading and condensation of the saturated mixture of flaky, pulverulent, and colloidal sediments, and temperature and pressure gradually rise with increasing depth of burial. These conditions promote molecular mobility and hence facilitate the development of new flaky minerals parallel to the bedding. Microscopic scales and aggregates of kaolins and hydromicas are common constituents of many clays and shales. These have been derived in part from the alteration of feldspars and other aluminous silicates during denudation, but doubtless in large part they have been developed through the action of the initiatory stage of metamorphism (anamorphism) upon precipitated colloids and residual particles of feldspar.

Low-temperature hydrothermal kaolinite has been identified by Cornu[43] and Buddington,[44] and Rogers[45] has shown that sericite is a low-temperature hydrothermal mineral in its relations to ore deposits. It now seems probable that crystalline kaolins and hydromicas also originate under the temperatures and pressures attained in the deeply buried clays. These flaky minerals, in large part secondary, and such original particles and aggregates as may become flattened, are believed to be essential to the development of shaly structure.

In most clayey rocks a parallel structure must inevitably result from the operation of compression and plastic flow. On the other hand, if fissility is dependent on the presence of an appreciable proportion of flat constituents, it also follows that, in sediments rich in colloids and, at the opposite pole, in granular silts, the development of such a structure is possible only to the extent that flaky or flattened constituents are formed. The fissility of shale is therefore comparable in some measure with the cleavage of slate. These structures are similar in commonly possessing a linear character, and this may be so pronounced as to yield a splintery fracture. As distinguished from mere

[43] Cited by W. Lindgren. Econ. Geol., vol. 10, 1915, p. 93.

[44] A. F. Buddington: An association of kaolinite with miarolitic structure. Jour. Geol., vol. 31, 1923, pp. 149-151.

[45] A. F. Rogers: Sericite a low-temperature hydrothermal mineral. Econ. Geol., vol. 11, 1916, pp. 118-150.

flakiness, this linearity in both shale and slate must be attributed directly to the effect of plastic flowage.[46]

OBSERVATION AND EXPERIMENT

These conclusions find confirmation in both observation and experiment. Thus Sorby, Tyndall, and other early experimenters demonstrated the competence of compression and flowage to generate a parallel structure in clay or wax by the development and orientation of flat particles, whether such constituents were originally present or not. Sharpe and Sorby developed the theory that rock-cleavage is due to compression of the rock and its expansion in planes at right angles. C. Darwin stressed the development of flaky minerals, such as micas, with the structure passing eventually into foliation. Sorby urged the rotation of platy particles of kaolin, mica, chlorite, etcetera, into parallelism and also the flattening of constituents. Reade and Holland have emphasized the part played by crystallization at the close of the process of compression, the platy minerals developing with ease in the directions at right angles to the compression. Like Darwin, they consider the original flat constituents of less importance.[47]

Cole[48] calls attention to the fact that dried lumps of some massive-looking clays when placed in water will break up along parallel planes, showing that there is a regular arrangement of the particles. He continues:

> "The fact that so many of these particles are platy becomes emphasized under the pressure of subsequent sediments, whereby the platy surfaces of the particles are brought into planes parallel with one another. The clay then becomes a shale, with regular planes of fissility, which are parallel to those of bedding. A certain amount of deformation of the rock accompanies this change, flow being set up parallel with the bedding and included fossils becoming sometimes flattened. This deformation is especially noticeable in the case of plant remains."

Van Hise,[49] through extensive investigations in the pre-Cambrian rocks of North America, was led to the conclusion that in these formations,

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[46] The writer is indebted to Dr. David White for the suggestion that the "shoe-peg" type of fissility, found in certain dense fine-grained clay shales, seems to conform with the rotation theory and the parallel alinement of elongate constituents. Information concerning such shales is desired, and specimens from which thin-sections might be prepared would be most welcome.

[47] Reviews and extended bibliographies are given by the following:
A. Harker: Rept. 55th Meeting Brit. Asso. Adv. Sci., 1885, pub. 1886, pp. 813-852.
C. R. Van Hise: 16th Ann. Rept. U. S. Geol. Surv., pt. 1, 1896, pp. 571-843.
C. K. Leith: U. S. Geol. Survey Bull. 239, 1905, pp. 13-20.

[48] Grenville A. J. Cole: Op. cit., p. 84.

[49] C. R. Van Hise: Op. cit., p. 635.

. . . "rock-cleavage is due to the arrangement of the mineral particles with their longest diameters or readiest cleavage or both in a common direction, and that this arrangement is caused, first and most important, by parallel development of new minerals; second, by the flattening and parallel rotation of old and new mineral particles; and, third, and of least importance, by the rotation into approximately parallel positions of random original particles."

Leith,[50] after investigation of a still wider range of materials, confirmed the validity of these conclusions.

Shaly fissility differs from the cleavage of such rocks, however, in being the product, not of tangential compression, but of relatively gentle gravitational adjustments, in consequence of which the new structure is developed approximately parallel to the bedding. Nevertheless, the fundamental principles are believed to be essentially the same, although for clays and shales more extensive microscopic research will be necessary before the relative importance of the various factors can be determined.

PRIMARY FISSILITY

Shaly structure might conceivably be developed by direct orientation of flaky kaolins, micas, and hydromicas during deposition. Such an origin is suggested by Geikie and Pirsson in the statements quoted elsewhere in this paper and a similar thought seems to be implied by some other authors. The thin, even lamination of the "paper shales" is undoubtedly an original structure, but this is evidently the product of sorting. Original shaly fissility is possible in homogeneous materials or unsorted mixtures only where flaky constituents are abundant in the sediment. Even so, in oozes and sludges that contain by volume from 60 to more than 85 per cent of water and in the presence of voluminous precipitated colloids, the regular deposition of minute flaky constituents in parallel position would seem to be impossible. In the Tertiary strata of California, for example, many of the beds that contain flat and elongate frustules of diatoms in large proportion, while commonly called shales, are nevertheless massive and structureless.

Perhaps the most favorable conditions for the development of primary fissility might be expected in fresh-water deposits, in which the proportion of colloidal matter is supposed to be generally smaller; but many such deposits are limited in area and have little or no shaly structure. It has also been suggested that the rhythmic deposition of colloids might produce a laminated or fissile structure, but experimental results seem to indicate that this mode of deposition is limited to small

[50] C. K. Leith: U. S. Geol. Survey Bull. 239, 1905, pp. 140-142.

tubes and takes place only in the presence of minute temperature gradients.

DOMINANCE OF SHALE IN THE OLDER STRATA

The overwhelming preponderance of shale over structureless clay rocks in the older and deeper sediments everywhere stands in striking contrast with the reverse condition in the later and shallower deposits. Beyond all question, this contrast is significant, and in the light of present knowledge it seems rational to attribute the structure primarily to the effect of loading through long periods of time. No other hypothesis of universal application seems possible.

Even in the older strata, however, not all of the clays have developed shaly structure. Several conditions have tended to preserve the massive character of some of these beds. The dense claystones underlying many coal seams are notable examples. They are generally deficient in potash and hence can have but little original mica or secondary hydromica. Most of them are fresh-water deposits and therefore presumably low in colloidal constituents and in plasticity, and many are relatively limited in areal extent. All of these conditions tend to restrict or prevent plastic flow.

Petroleum and Natural Gas

THE PROBLEM OF ORIGIN

Brief reference may be made to certain features in the natural history of the hydrocarbons that seem to be closely related to the history of shale. For this purpose the organic origin of petroleum and natural gas is assumed.

The colloidal organic (humic) matter of many clays and shales yields on distillation various liquid and gaseos hydrocarbons that resemble somewhat the natural products. The strata accompanying these substances in nature, however, generally show no evidence of having been subjected to the temperatures of laboratory distillation. Probably a combined distillation and cracking process at moderate temperatures will best account for the products actually found, the hydrocarbons perhaps first taking the form of heavy, viscous bitumens and gradually breaking up into lighter compounds.

McKee and Lyder[51] have found that the organic matter in many oil shales, upon heating between 400 and 410 degrees C., without access of air, yields a heavy solid or semi-solid bitumen which is soluble in ben-

[51] R. H. McKee and E. E. Lyder: The thermal decomposition of shales. Jour. Ind. and Eng. Chem., vol. 13, 1921, pp. 613-618, 678-684.

zene and carbon bisulphide and which gradually decomposes into lighter hydrocarbons. The complex reaction is endothermic, requiring 421 to 484 calories for each gram of oil and gas produced.

Oily substances supposed to resemble petroleum have been reported from decomposing seaweeds on the coasts of Sweden, Sardinia, the Red Sea, and the Levant. The humic colloids in clay sediments may yield similar substances both during accumulation and later, under the influence of condensation, kneading, plastic flow, and slowly rising temperature. In many regions the process has been intensified by lateral compression[52] and in some by the heat and stresses of igneous intrusion.

McCoy[53] made a suggestive experiment on oil shale, which yielded 25 gallons per ton on distillation but gave no test for petroleum with solvents. Cylindrical columns of this material were subjected to compression in thin-walled metal tubes, which bulged and permitted plastic deformation. The crushing strength of the shale was about 3,000 pounds per square inch. It was subjected to pressures of 5,000 to 6,000 pounds, corresponding roughly to depths of 4,000 to 5,000 feet. After compression and deformation strong petroleum coloration was obtained with solvents, and globules of oil were visible under the hand lens.

From this experiment McCoy concluded that liquid hydrocarbons originate in shale from solid bituminous materials at ordinary temperatures and under such pressures as exist at the depths of oil-bearing horizons, and, furthermore, that such compounds are formed only in areas of differential movement. It is to be noted, however, that the temperature attained under compression was not determined, and hence the results are not entirely conclusive. Washburne[54] thinks the effects are attributable to heat rather than pressure. Whatever the immediate cause, they resulted from the action of flowage under differential pressure, and presumably similar transformations might occur in shale at corresponding depths.

Where lateral compression has operated, even without the development of recognizable deformation, it must have contributed to the plastic kneading of the finer sediments. Thus it has doubtless promoted the breaking up of organic materials into liquid and gaseous hydrocarbons, and it may be largely responsible for those lighter products that are so abundant in the petroleum of the older formations.

[52] See David White: Loc. cit., pp. 4-17 (179-192).

[53] A. W. McCoy: Notes on principles of oil accumulation. Jour. Geol., vol. 27, 1919, pp. 252-262.

[54] C. W. Washburne: Jour. Geol., vol. 28, 1920, pp. 366-370; also A. W. McCoy: Idem, pp. 371-373.

MIGRATION AND CONCENTRATION

Whether the origin of petroleum be attributed, on the one hand, chiefly to geochemical processes due to deep burial, or, on the other hand, to the action of anaerobic bacteria and bacterial enzymes in muddy waters and in semi-liquid sludges and soft clays, the liquid hydrocarbons must begin their existence as submicroscopic globules in the connate water; and along with the water they must eventually be squeezed out of the fine sediments during condensation. It is difficult to imagine their escape in considerable quantity in any other manner.

King's experiment[55] demonstrates that water eliminated from fine sediments during condensation passes in part downward into underlying sands, where these offer the path of least resistance. Globules of gas and oil suspended in this water may thus be transferred in great quantities into reservoir rocks beneath their level of origin.

Differences in the character and movements of oil-field waters and in the chemical and physical properties of the oils themselves show that in many regions there is little or no vertical migration between reservoir-rocks and that thin "shells" and partings of clay and shale are effective barriers, even where enormous differences in pressure exist. Many such partings are too slight to be detected in drilling and are only inferred from the striking contrasts above and below certain sharply-defined horizons. Hence it must be concluded that after the early watery stages the clay rocks quickly become impermeable. Seelheim's experiments, previously referred to, indicate that this condition is attained when the sediment has a mass density of 1.95 to 2.00 and still retains some 20 per cent of water.

Hence with the development of fissility it may well happen that such portion of the primal emulsion of water, oil, and gas as still remains in the mother-shale will follow in part this new structure, perhaps up the depositional slope into coarser shoreward sediments. Even in this direction, however, the rock must soon become so nearly impervious as to offer great resistance, and the possibility of movement must depend largely upon the continual modification of the interstitial spaces by the kneading and jigging processes.

On the other hand, as the liquids are gradually eliminated and the strata become even slightly compacted new avenues of escape may appear in the form of joint cracks and fissures. McCoy[56] has shown how these openings may serve as ducts across the bedding into sands that

[55] F. H. King: 19th Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 79, 80.
[56] A. W. McCoy: Loc. cit., p. 253.

would otherwise be effectively sealed off by intervening shale. Thus is released an appreciable proportion of the petroleum that might otherwise remain permanently locked in the shale. The joints and fissures also facilitate the redistribution of oil and gas and their escape to the surface. Harrison[57] concludes that in the Rocky Mountain region "a reasonable amount of faulting, providing means of escape for the gas, may be a favorable feature in a dome where oil is desired"; and furthermore that in steeply tilted or sharply folded strata the hydrocarbons may be conducted laterally or even upward by fissures into sands that lie stratigraphically lower.

Cook[58] has shown that the capillary interchange of oil and water involves the movement of a film of water along the walls of the opening, and within this water-lined tube the oil flows in the opposite direction. Besides an indefinite lower limit to the size of openings through which this double flow can take place, he also found that the movement is stopped by minute bubbles of gas.

Capillarity and the greater adhesion between water and the rock-minerals probably accounts for the transfer of little oil from clay or shale into adjacent sands. In the denser clays most of the openings are doubtless too small to permit the necessary double flow; but of greater importance is the fact that after the deposition of overlying strata the contained liquids are under continuous compression. The water and hydrocarbons are freely expelled in large volume during the earlier stages of condensation; but in all stages a constant outward pressure is maintained and the entangled liquid steadily escapes from the clay until the interstices are reduced to such minute dimensions (about 6 millimicrons) that the films are held rigid by the attraction of the walls. The plastic molding of the constituents upon one another with the increasing pressure and rise of temperature may gradually eliminate many of these subcapillary openings, but the movement of the liquid involves such tremendous resistance that much of it becomes inextricably entangled. Capillary interchange of oil in such a shale with water in an adjacent sand would seem to be out of the question. Furthermore, a thin layer of firm clay that had exchanged oil for water, assuming such an interchange possible, would constitute an impervious barrier against further movement. From a practical viewpoint, therefore, it seems clear that capillarity may be disregarded as a factor in the extraction of oil from the denser source-rocks.

[57] T. S. Harrison: Some ideas regarding oil accumulation in the Rocky Mountain region. Bull. Am. Asso. Petr. Geol., vol. 7, 1923, pp. 667, 668.

[58] C. W. Cook: Study of capillary relations of oil and water. Econ. Geol., vol. 18, 1923, pp. 167-172.

Somers,[59] whose paper has appeared while this was in process of revision, is doubtless wholly correct in his contention that the principal cause of migration of the hydrocarbons from the shale into the reservoir-rocks is the compacting of the shale. Important accessory processes in both the condensation of the shale and the elimination of the interstitial fluids are the stresses and movements induced by jigging vibrations and tidal kneading, with accompanying dehydration, molecular rearrangements, and movements of the constituent particles.

Once in the sands the minute globules of oil suspended in water are subject to the operation of hydraulic processes, which may transfer them into other portions of the same beds, or into overlying beds, or into fissured and fractured zones, or into porous and cavernous formations of the old land upon which these strata may overlap. Thus swept along by the water these substances may accumulate in anticlines, domes, or other structures, through gravitational influence. The lower density of the oil and gas will aid in taking them up the dip of the porous strata but will hinder their movement down the opposite limb. The same conditions will favor the segregation of disseminated oil in the upper part of a reservoir-rock that is only partly filled; hence "cores taken from the edge of an oil sand sometimes show the upper part saturated with oil while the lower part is barren, and often there is no shale parting between the two."[60]

In the primal emulsion stage the hydrocarbons must move with the enveloping water as though they were in solution wherever the openings traversed are larger than the suspended globules, regardless of the rate of flow. So long as these conditions maintain the globules of oil and gas offer no resistance to passage through the interstices of the rock. Eventually coalescence builds up droplets of greater diameter than the connecting channels. Then, since water has greater adhesion for the rock-minerals, the oil is restricted to larger and larger openings, and eventually to the largest. In such open-textured parts of the reservoir it must remain until the accumulation fills the voids and oil becomes continuous from one to another, to the exclusion of water.

Russell[61] has shown that where oil thus accumulates in sands in volume only a few feet in depth it will migrate by virtue of its buoyancy, threading its way upward by difference in head between the oil and water. Free

[59] R. E. Somers: Origin, migration, and accumulation of petroleum. Eng. and Mining Jour. Press, vol. 115, January 13, 1923, pp. 66-69.

[60] J. E. Elliott: Technique of core-drilling. Mining and Metallurgy, vol. 4, October, 1923, p. 516.

[61] W. L. Russell: Some experiments on capillarity and oil migration. Econ. Geol., vol. 19, 1924, pp. 35-61.

gravitational segregation of smaller bodies is possible, however, in the greater open spaces of such reservoirs as course sands, conglomerates, breccias, fissured zones, and cavernous lavas and limestones; and accumulations in such reservoirs may also be readily transferred or flushed out when active hydraulic conditions are established.

Further Research Needed

THE PITFALLS OF DEDUCTION

In the absence of exact data much of the discussion of these problems is necessarily deductive—an attmept to reason out what must be, pending a more thorough knowledge of the actual facts. Hence a word of warning seems pertinent against over-confidence and over-indulgence in this method in inductive science, which can rest securely only on a broad foundation of observation and experiment. Deduction is a valuable implement of research, particularly in the formulation and testing of theories; but without frequent and rigorous tests it may lead to erroneous conclusions.

Where conditions and fundamental principals are but imperfectly understood no result of reasoning can take the place of accurately determined facts. Like extrapolation in mathematics, the method is theoretically sound, but in practice special precautions are necessary. One of the outstanding triumphs of Greek thought is the development of geometry, which is the best type of deductive reasoning; but in the realm of nature this long had the unfortunate influence of emphasizing the deductive method to the neglect of the need of verification.

Unverified deduction still vitiates much of the current theory of sedimentation and of the whole youthful and immature science of geology, for that matter. General principles have been too readily assumed, and the traditions of the elders have been handed down with all the weight of authority. Moreover, the appeal to facts is tedious and laborious, and often the results are disconcerting. Fortunately the disclosures of the mine stope, the core drill, and the engineering excavation are swayed by none of these considerations; and the alert worker who toils over the waste places of the earth acquires a wholesome spirit of irreverence toward authority. Thus are slowly accumulated the fundamental data for the reorganization and advancement of geologic theory.

In the meantime "geologists do well to walk humbly, and punctiliously to admit that the geologic principles controlling the distribution of oil and gas have as yet been discovered only in part, and that what remains

yet to be learned is probably vastly more than what is already known."[62] The alert student will therefore entertain as many alternative hypotheses as possible and will take care that he does not commit himself unreservedly to any one of them.

EXACT DATA REQUIRED

Hence, while recognizing a general tendency in the clay rocks to develop fissility under compression, as indicated by both observation and experiment, it must be conceded that the efficacy and ultimate effects of many of the factors involved can as yet be but roughly estimated. Few observations, for example, have been recorded concerning the influence of tidal oscillations on sediments. In varying degree a similar reservation applies to the other processes that affect the deposition and condensation of the strata and, with still greater force perhaps, to the origin and accumulation of petroleum and natural gas.

Abundant opportunity for investigation will doubtless continue to be furnished, however, by excavations in both hard and soft materials in engineering works, in mining and core-drilling explorations, and in steadily deeper drilling and eventually shaft-mining for petroleum. Such investigations must be attacked by the geologist with constantly increasing refinement and accuracy of method.

The growing demand for quantitative data has now been recognized in many branches of geology. The influence of engineering standards, felt first in the mining regions, has been extended to all modern geologic mapping, and exact methods in every branch of geology are becoming more and more imperative. Hence the earlier qualitative tests must be repeated and amplified under more rigid control and the results recorded with a commensurate degree of accuracy. In the light of such experimental data and the critical records of the geologist in field and laboratory, deductive hypotheses may be properly revised and corrected—or perchance found wholly inadequate and rejected.

Summary of Conclusions

1. Most clays contain abundant scales and scaly aggregates of crystalline kaolins and hydromicas, much quartz, commonly some remnants of feldspar, and several minor constituents. Some also have considerable sericite. Besides these there is generally much amorphous-looking material, commonly supposed to be kaolin, which may include a variety of crystalline and colloidal substances.

[62] David White: Loc. cit., p. 1.

2. Freshly-deposited clay may contain more than 85 per cent water by volume and may have a mass density, or apparent specific gravity, below 1.25. In general the density depends on the weight of overburden and the length of time during which this pressure has operated. The firm rock may eventually retain but a small fraction of the original thickness.

3. Cohesion, or "welding," of particles in the consolidation of clay rocks is favored by the vast number of points and surfaces of contact; the great volume of interstitial water, supplemented by the dehydration of minerals and colloids may also promote cementation; and doubtless generally there is much recrystallization.

4. *Shale* and *shaly* are vague and ill-defined terms. They should be restricted to clay rocks that possess a capacity for splitting into flakes, thin chips, and wedge-like fragments approximately parallel to the bedding—a structure that is made conspicuous by weathering. These should be distinguished from massive sediments (claystones, mudstones) and from thinly laminated bedded strata ("paper shales").

5. Clay, on becoming shale, generally loses more than half its combined water, and there is little or no further dehydration when it becomes slate. Hence in shale much of the hydromica has already attained the stage of sericite or very nearly so, and in the transformation into slate this constituent merely undergoes mechanical rearrangement and recrystallization into larger flakes.

6. The mechanical basis of fissility in shale is the parallel arrangement of flat and elongate constituents. These are partly original constituents of the sediment, but they are generally in large part of secondary origin.

7. This structure is due primarily to gravitational compression of clayey sediments—a process that flattens soft particles and flocculent aggregates; orients flat constituents, both primary and secondary, in parallel horizontal arrangement; and leads to the development of flaky secondary kaolins and hydromicas.

8. Second in importance only to gravitational compression is plastic flow, which aids in the orientation of tabular particles and also adds a linear structure due to the elongation of some constituents and the parallel arrangement of elongate constituents in the direction of flow.

9. Important accessory processes are tides, waves, earthquakes, seasonal oscillations, and variation in atmospheric pressure, various com-

binations of which may give rise to, and in turn be accentuated by, offshore slumping of sediments.

10. Original fissility, due directly to deposition, is perhaps mechanically possible, particularly in fresh-water sediments; but conditions favorable to its development are probably seldom realized.

11. The theory of the secondary nature of shaly fissility affords a rational explanation of the preponderance of shale over massive clay in the older and more deeply-buried formations, in contrast with the reverse conditions in superficial and shallower deposits.

12. Petroleum and natural gas are derived from the unstable organic (humic) colloids, perhaps in part during the deposition of the clays and silts, but doubtless largely through the action of the processes concerned in condensation and the gradual rise in temperature due to friction and depth. In some regions lateral compression has also come into play and in some the heat and stresses of igneous intrusion.

13. Condensation slowly squeezes out the fluid hydrocarbons from the fine sediments, along with the entrapped water; but in large quantities they may become inextricably entangled in the dense clay strata.

14. With the development of fissility an increasing proportion of the escaping fluids doubtless follows this structure, which may lead up the depositional slope and into more open shoreward deposits.

15. When the strata have attained a slight degree of firmness joint cracks and fissures afford more open channels of escape from clay and shale and for migration across the bedding. They also permit the loss of much oil and gas to the surface.

16. Capillarity may be disregarded as a factor of economic importance in the transfer of petroleum from the clays and shales into the reservoir rocks.

17. Migration within the sands may be largely effected by hydraulic processes and by virtue of the buoyancy of oil in water.

18. Accumulation results from accidental lodgment in the interstices of the less compressible sediments (sands and gravels) and in porous, fissured, brecciated, and cavernous formations generally where favorable structures are so capped as to form suitable traps.

Acknowledgments

This paper, in preliminary form, was presented by title and abstract at the Ann Arbor meeting of the Geological Society of America, December 28-30, 1922. A portion of it was also read and discussed at the meeting of the Society of Economic Geologists in New York City, May 18, 19, 1923. The author acknowledges his indebtedness to Dr. George H. Ashley and Professor Edward B. Mathews, who participated in the discussion. Special acknowledgments are also due to Dr. David White and Mr. E. DeGolyer, who kindly read and criticised an early draft of the manuscript.

In its present form the paper has been extended somewhat in order to cover more fully the various aspects of the subject, particularly some of the questions which arose in discussion. The author alone, however, is responsible for the conclusions, except as otherwise noted, and for the form and content of the paper as a whole.

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GEOLOGY AND PHYSIOGRAPHY OF THE PERUVIAN CORDILLERA, DEPARTMENTS OF JUNIN AND LIMA *

BY DONALD H. MC LAUGHLIN

(Read before the Cordilleran Section April, 1924)

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Introduction

General

The Peruvian Cordillera offers a field for geologic research so vast that in spite of the work of many investigators it still possesses the allurement of an almost virgin country. The present conception of the regional geology has of necessity been built up from scattered information rather than from comprehensive surveys, and its accuracy obviously depends upon the degree to which the studies that have been made afford a fair sample of the many features of the Cordillera. The published works of Raimondi, Bravo, Steinmann, Lisson, Bowman, and others and the many papers that have appeared in the bulletins of Peruvian organizations have already provided an excellent fund of information and a basis for further advancement; but the area to be studied is so great that all existing work hardly amounts to more than a very partial examination. The stock of available knowledge still needs to be strengthened by many more studies before a reasonably accurate conception of the whole can be deduced. It is with the hope of contributing to this common store of data and of adding other samples for inclusion in the regional average that these notes on one section of the country have been prepared.

The present paper deals largely with the regional geology of parts of the high western range and the extensive central plateaus, chiefly in the departments of Junin and Lima. It is a partial summary of the information and ideas which have accumulated in the course of the work of the Geological Department of the Cerro de Pasco Copper Corporation and is based both on the results of detailed studies in the important

mining centers and on more widespread but less exact work of an exploratory nature throughout central and northern Peru.

The geology of the desert canyons on the Pacific side and of the wooded montaña country on the eastern slope has not been sufficiently studied in the course of our work to permit us to include opinions on it. The generalizations expressed in this paper are limited to the region of high altitudes with which we have greater familiarity. The economic geology of the district under consideration is discussed in this paper only in very general terms.

ACKNOWLEDGMENTS

All statements concerning the structural geology and petrology are based on the work of the Geological[1] Department of the corporation, but in matters pertaining to paleontology determinations previously published are followed unless otherwise specified. Acknowledgment of ideas gained from other writers is mentioned in the text as occasion requires, but the work of Mr. José J. Bravo, the director of the Cuerpo de Ingenieros de Minas del Peru, requires special mention to express our appreciation of its high value.

GEOGRAPHY

The region to be described lies in the higher portions of the Andes to the east of the city of Lima. It extends from about 40 miles north of Cerro de Pasco to a similar distance south of Huancayo, a total distance of 200 miles or more along the axis of the Cordillera. It includes most of the western range between the latitudes of 10° and 12° 30′ south and extends over the plateau region to the edges of the eastern range.

The western range (the Cordillera Occidental) in this part of the Andes is the Continental Divide. It forms a lofty, unbroken wall, with numerous peaks 17,000 feet or more in elevation and no passes lower than 15,000 feet for great distances. Toward the west it plunges to the deserts of the Pacific coast through a country of deep canyons and sharp ridges; toward the east it breaks away abruptly to the general level of the rolling hills and grassy pampas of the plateau region, which lies only a few thousand feet lower.

[1] The work of Messrs. W. F. Walker at Cerro de Pasco, M. G. Edwards at Morococha, H. E. McKinstry at Casapalca, H. K. Armstrong, Rogers Peale, and D. D. Smythe has aided to an important degree in the regional geologic studies herewith presented. I am also indebted to Mr. L. C. Graton for discussion and criticism, both in Peru and in the United States. The first systematic geologic work at Cerro de Pasco and Morococha was started under the direction of Mr. J. M. Boutwell, who was consulting geologist for the corporation from 1916 to 1919, and its importance is keenly appreciated by all members of the present staff.—D. H. McL.

The central plateau country is a land of gentle relief, ranging from 13,000 feet to 14,500 feet in elevation, traversed here and there by a few broad rivers either in wide, open valleys or more commonly in deep, precipitous canyons.

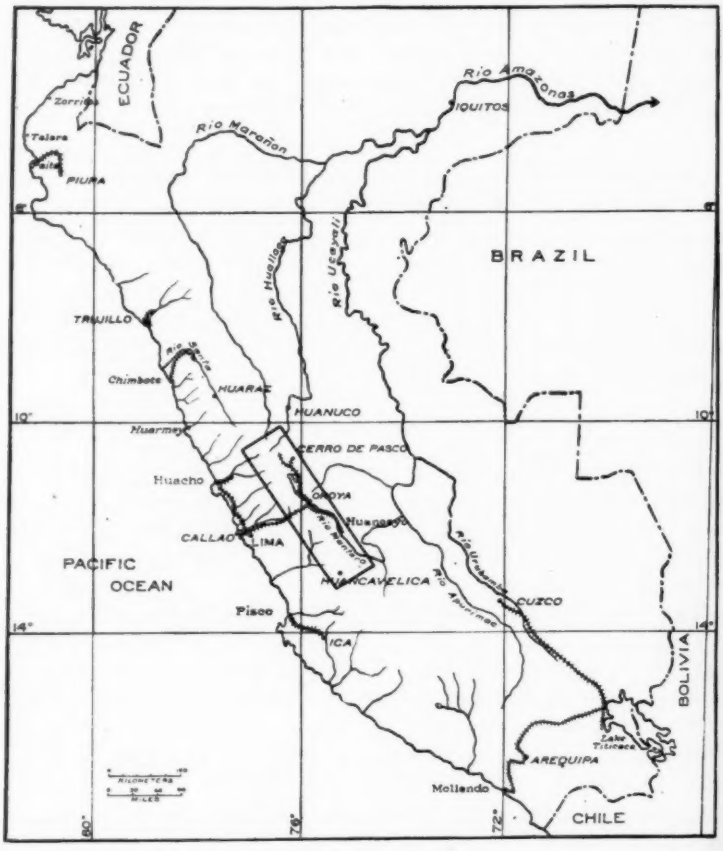

FIGURE 1.—*Map of Peru*

Showing location of country discussed in this paper, outlined approximately by small rectangle. Geological Department, Cerro de Pasco Copper Corporation.

The eastern range, which lies from 40 to 60 miles from the Continental Divide, is a well-marked line of high peaks divided by deep transverse drainage courses into a series of separate mountain groups.

The rivers on the Pacific side are violent torrents, flowing directly to the ocean with steep gradients. The Rio Rimac, which descends through Lima, is a well-known example. The eastern streams are larger and collect their waters over greater basins. Of these, the Mantaro River,

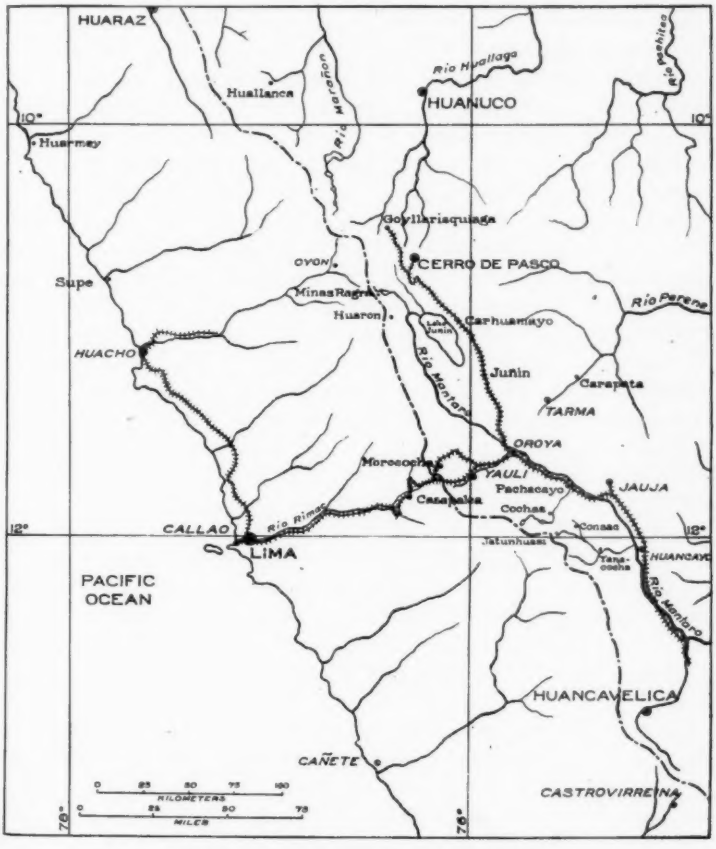

FIGURE 2.—*Map of Portion of central Peru*

The area indicated is largely in the departments of Lima and Junin. Geological Department, Cerro de Pasco Copper Corporation.

which drains the basin of Lake Junin and flows south past Oroya and through the Huancayo Valley, and the Marañon and Huallaga rivers, which flow north through tremendous canyons, are the most important

streams in the area under consideration. The divide between northern and southern drainage basins passes from the western range to the eastern through the city of Cerro de Pasco and forms a belt of high land which is known as the Nudo de Pasco. These master streams unite in the Amazon. Shorter streams here and there cut through the eastern range, but do not drain more than a small area of the plateau country.

The Central Railroad of Peru, the famous road built by Meiggs in the seventies, ascends the valley of the Rimac from Callao and Lima, climbs past Casapalca, and passes by tunnel through the crest of the western range at Ticlio, where it attains an altitude of 15,665 feet. On the eastern side the road descends more gradually past the old mining town of Yauli to Oroya (138 miles from the coast) and continues down the Mantaro River with an easy gradient to its terminus in the Huancayo Valley, 215 miles from Callao, at an elevation of 10,690 feet. From Oroya the Cerro de Pasco Railway extends 82 miles to the north, across the broad pampa of Junin, to the city of Cerro de Pasco, at an altitude of 14,200 feet, on the divide between the Mantaro and Huallaga rivers. A branch line from the Cerro de Pasco road extends 26 miles to the northwest, to the coal mines at Goyllarisquisga, situated at the edge of the pampa country, on the brink of abrupt canyons of the Huallaga drainage.

The hills and pampas of the plateau country are grassy and support large flocks and herds. Above 15,000 feet the scenery becomes Alpine in character, with the grasses giving way to mosses, bare rock, and ice. Below an elevation of 12,000 feet brushes and scattered trees begin and an attractive flora, not unlike that of barer parts of the Californian Coast ranges, appears. The likeness is further emphasized by the extensive cultivation of eucalyptus in many valleys. On the east, this type of country passes gradually into tropical jungles; on the west, into deserts.

The high pampas grant a living only to scattered pastoral communities. The valleys, however, support a farming population which has established important villages in the broader valleys or on terraces on the sides of the greater canyons from the 12,000-foot elevation downward.

Mining at present is the most important activity. The work of the Cerro de Pasco Copper Corporation, with mines at Cerro de Pasco, Morococha, Casapalca, and Goyllarisquisga, and a smelter at Oroya, supports a large population. The mines operated by Sr. E. E. Fernandini, the Vanadium Corporation of America, and the Companie des Mines de Huaron are also important factors in the economic life of the region.

The principal towns are Cerro de Pasco (the capital of the Depart-

GEOLO

	GOYLLARISQUISGA	CERRO DE PASCO	JATUNHUASI	M
QUATERNARY	Glacial Deposits	Glacial Deposits	Glacial Deposits	Gl
TERTIARY (?)	Llachsa porphyry	Cerro qtz mon porphyry	Caja Real porphyry	More Anti
		Rumiallana agglomerate Lourdas tuff		
	Pocobamba formation	Calera limestone Shuco limestone conglomerate	Tertiary red beds	
CRETACEOUS SENONIAN	——	——	?	
COMANCHIAN VRACONIAN APTIAN VALANGINIAN (WEALDEN)	Machay limestone (Chulec member) Goyllarisquisga - Jatunhuasi sandstone Amygdaloid.		Machay limestone Goyllarisquisga - Jatunhuasi sandstone Diabase	Mach Tor Tor
JURASSIC LIAS	Pucara limestone	Paria limestone	Condorsinga limestone	Poto Mon
TRIASSIC		Ulachin limestone		
CARBONIFEROUS (?)	Mitu formation			Cat (Ya
SILURIAN (?)	Excelsior series	Excelsior series		Exc
PRE-CAMBRIAN (?)				

GEOLOGIC COLUMN

...o DE PASCO	JATUNHUASI	MOROCOCHA	CASAPALCA	GENERAL	SYMBOL AND ABBREVIATION	THICKNESS (MAXIMUM)
...ial Deposits	Glacial Deposits	Glacial Deposits	Glacial Deposits	Glacial Deposits Terrace gravels	Qg	400 ft. (estimated)
...x mon porphyry	Caja Real porphyry	Morococha qtz. mon. Anticona intrusives	Carlos Francisco trachyte porphyry	Tertiary intrusives	cm Ti mi ai eft	
...e agglomerate ...tuff			Rio Blanco formation Bella Vista limestone Tablachaca volcanics	Tertiary volcanics	ra rbf lt tv Tv	800 ft. (ra) (estimated) 1000 ft. (lt) (measured)
...limestone ...limestone ...conglomerate	Tertiary red beds		Casapalca red beds	Tertiary red beds	pf cl slc orb Trb	6000 ft (orb, est.) 2500 ft (pf, est.)
——	?	——	——	Jumasha limestone	jl	>1500 ft. (estimated)
	Machay limestone Goyllarisquisga - Jatunhuasi sandstone Diabase	Machay limestone Toribio sandstone Toribio basalt		Machay limestone Pariatambo member Chulec member Goyllarisquisga - Jatunhuasi sandstone Flows and sills	ml gjss	>2000 ft. (estimated) 2600 ft (measured)
...mestone	Condorsinga limestone	Potosi limestone Montero basalt		Pucara limestone	pl mb	>3000 ft. (Paria, est.) 1000 ft. (Pucara, meas.)
...in ...limestone				Uliachin limestone		
		Catalina (Yauli) volcanics		Yauli volcanics Mitu formation	cv mf	2500 ft. (estimated) 800 ft (measured) 1200 ft (estimated)
...or ...series		Excelsior series (Yauli)		Excelsior series	es	10 000 ft (estimated)
				Carpapata schist Gneiss		

ment of Junin), Oroya (the present smelting center), Morococha, Casapalca, and Yauli (mining centers), and Junin, Tarma, Jauja, and Huancayo (towns dependent on agriculture or stock raising).

The climate, except at the high altitudes, is mild. Two seasons are marked—six months of wet weather, corresponding to the southern summer (November to April, inclusive), and six months of dry weather, corresponding to the southern winter. The dry season is a little colder than the wet season, but it is by far the more agreeable time of year. The grassy hills become a ripe yellow, the trails are firm, the days bright and cheerful, and traveling is a pleasure. Above 14,000 feet the precipitation is generally hail or snow. Storms occur at all seasons, but in the dry months they are usually of only local character and pass quickly. Even at 14,000 feet only thin films of ice form during the coldest nights and below 15,000 feet ice rarely lasts later than 10 o'clock on clear mornings. The temperatures in the sun are high, and on northern slopes snow melts with surprising rapidity.

The greatest run-off, both from the high ranges and from the plateau country, is in January and February, when precipitation is heaviest and temperatures are highest. In the dry months, when water is needed, mean temperatures unfortunately are lowest, and the melting of glaciers, even at elevations as low as 15,500 feet, almost ceases; consequently a glacier peak in this region does not possess a value for water storage comparable to snow and ice fields in western United States.

Geology

Geologic column

A thick series of somewhat metamorphosed shale and sandstone, possibly of Silurian age, forms the base of the geologic column throughout the high country, in the portion of the Andes under consideration. To the east older schists and gneisses appear, but they are not exposed in the plateau region or along the western range, which are largely formed of Mesozoic limestones and sandstones with subordinate deposits probably of Carboniferous age, and later sediments with associated volcanic rocks. The Mesozoic beds are dominant in the central areas and in the northern part of the western range, but toward the south the crest of the Cordillera is carved almost entirely from the overlying red beds (probably of Tertiary age) and from volcanic breccias and tuffs which accompany them.

The various formations, with their thicknesses, are given in the attached table. The sequence is believed to be well established and little

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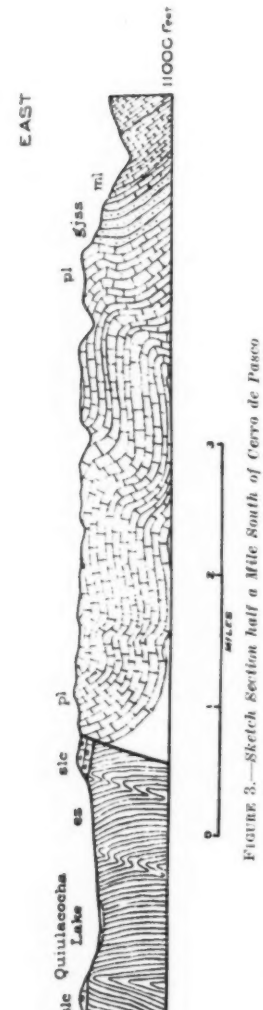

FIGURE 3.—*Sketch Section half a Mile South of Cerro de Pasco*

doubt is felt concerning the correlations, but the statements of age must be questioned in some cases, as indicated. Where surveyed sections exist, the measured thicknesses are stated; otherwise, merely an estimate of the maximum observed thickness is given. The symbols and abbreviations are those used on the geologic sections which illustrate the paper.

BASAL FORMATIONS

Metamorphic rocks.—The mica schists, which occur in a broad band along the upper edge of the montaña country, are probably the altered product of the oldest sediments of the region. Numerous small and large intrusions, mostly medium to coarse grained rocks with gneissic texture, accompany the schists. They lie, however, in a zone to the east of the country studied in our work and very few data concerning its details are at hand. Toward the west the metamorphic rocks plunge so far beneath the thick accumulation of later sediments that even the deepest canyons in the central highlands have failed to expose them. They are best seen in the gorges which dissect the eastern range. At Carpapata, below Tarma, a good section is shown along the Chanchamayo road.

Excelsior series.—The oldest formation in the higher country, with which we are primarily concerned, consists of an exceedingly thick series of sediments, originally shale and interbedded sandstones and shales, now regionally altered into their slightly metamorphosed equivalents. It is exposed in the canyons of the upper tributaries of the Huallaga River, where deep erosion has cut through the overlying sediments, but it also appears at high altitudes near Cerro de Pasco and in other districts where faulting

or folding has brought the deeper rocks within range of erosion (figure 3). Well-known exposures occur in the valley at Tarma, along the east side of the Huancayo Valley and near Yauli.

The prevailing member of the series is rather difficult to name in an entirely satisfactory way. Where best exposed, it is a dark fissile rock with an indefinite slaty or schistose texture. In many places the rock grades into a fairly typical phyllite, and locally, with numerous thin lenses of quartz and more prominent development of the micas, it approaches a true schist. The parallel structure is always well marked, but is never perfect enough to allow any of the rock to be termed a slate, although this name was commonly applied to a conspicuous member of the formation by early writers on the Cerro de Pasco district. Thin quartzite beds are prominent throughout the entire series, and over large areas become sufficiently abundant to make the rock merely a succession of quartzite layers one-half to 6 inches thick, separated by numerous partings of black micaceous shale.

The beds of the members of this series of altered sediments generally dip at high angles and strike most commonly north 10 degrees to 40 degrees west. A far more intense history of folding, faulting, and accompanying alteration is shown in these rocks than in the later formations. Sharp folds and minor breaks appear in nearly every good exposure.

All later sediments rest unconformably on the rocks of the Excelsior series. The formation is clearly older than the Mesozoic limestones and is likewise earlier than a conglomerate and sandstone formation, probably of Carboniferous age, which lies beneath determined Jurassic sediments. No definite fossils have been found as yet in the Excelsior beds in this part of Peru. Graptolites, indicative of the Silurian, have been identified by Bravo in material from similar beds near Ambo,[2] but further study is required to establish the correlation between these deposits and the Excelsior series. A Silurian age has been argued for corresponding sediments near Tarma,[3] but as yet the evidence is not final.

CARBONIFEROUS FORMATIONS

General.—The thick limestones of Carboniferous age, which are so prominently developed in southern Perú,[4] are lacking or are very subor-

[2] N. G. Ochoa: Recursos minerales de la Provincia de Huanuco. Bol. del Cuerpo de Ingenieros de Minas del Perú, No. 9, 1904, p. 18. According to Bravo, the specimens correspond to the genera *Monograptus* and *Climacograptus*.

[3] Gustavo Steinmann: Observaciones geologicas effectuadas desde Lima hasta Chanchamayo. Bol. del Cuerpo de Ingenieros de Minas del Perú, No. 12, 1918, p. 23.

[4] Isaiah Bowman: The Andes of southern Perú, pp. 241 to 247. New York, 1916.

dinate in the area under consideration. Fossils from the country east of Tarma[5] and east of Carhuamayo[6] (a town on the Cerro de Pasco Railway), that are indicative of both marine and continental Carboniferous sediments, have been described, but as yet no one has examined the formations in detail. Some thin beds of dirty coal containing fossils of *lepidodendron* and *sigillaria* have been found in the sediments east of Carhuamayo. The deposits are of no commercial importance, but interesting as the only occurrence of Carboniferous coal known in this part of Peru. The Mitu sandstone in the Goyllarisquisga district may possibly be correlated correctly with these beds, but as yet no fossils of Carboniferous age have been found in it or in any other sediments studied in the course of our work.

Mitu formation.—In many parts of the region northwest of Cerro de Pasco the first beds, which rest on the upturned and eroded edges of the Excelsior series, consist of reddish and gray sandstone capped with a sandy conglomerate. The conglomerate is composed of subangular fragments of quartz and slightly worn, flat fragments of phyllite or imperfect schist held in a sandy matrix. The material appears to have been derived largely from the underlying altered sediments of the Excelsior series. The formation is of variable thickness. It is prominently exposed along the steep canyon slopes below Goyllarisquisga, particularly in the cliffs above the village of Mitu, where it attains a thickness of about 800 feet. The conglomerate member at the top is only about 50 feet thick, but it is a persistent bed and generally forms a bold outcrop (see figure 4). A similar formation which crosses the valley above Tarma appears to be somewhat thicker.

No fossils have been found in these sediments and their age is indeterminate, except that they are later than the metamorphism of the Excelsior beds, and that they lie below limestone of Jurassic age and are possibly separated from it by a slight structural unconformity. Lithologically they are similar to the continental Carboniferous beds east of Carhuamayo and may be provisionally correlated with them.[7]

Catalina (Yauli) volcanics.—A thick series of volcanic beds, mostly pyroclastic rocks of andesitic composition, rests on the phyllites near Yauli and is overlain by limestone of Mesozoic age. The formation consists of beds of light buff and gray tuffs and thicker masses of purplish gray volcanic breccia and agglomerate. Flows occur, but are subordinate.

[5] Gustavo Steinmann: Op. cit., p. 24.

[6] C. I. Lisson: Bol. de Minas, Industrias y Construcciones, publicado por la Escuela de Ingenieros. Serie II, T. XIV, N. 1-3, Lima, 1922, p. 5.

[7] Steinmann considers the beds near Tarma probably Triassic, but submits no definite evidence. Op. cit., p. 23.

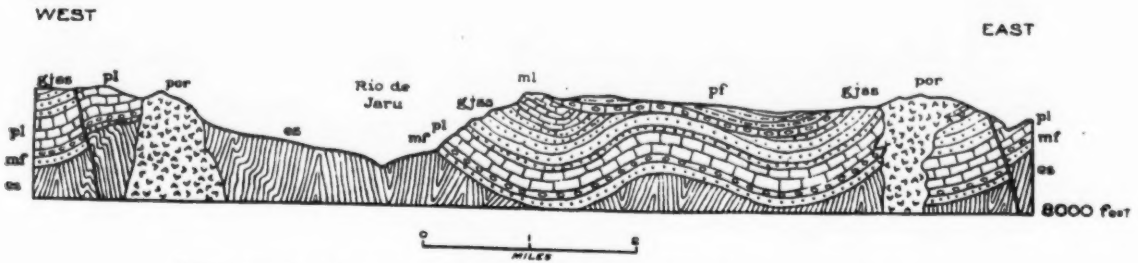

FIGURE 4.—*Sketch Section, North 70 Degrees East, about two Miles South of Goyllarisquisga*

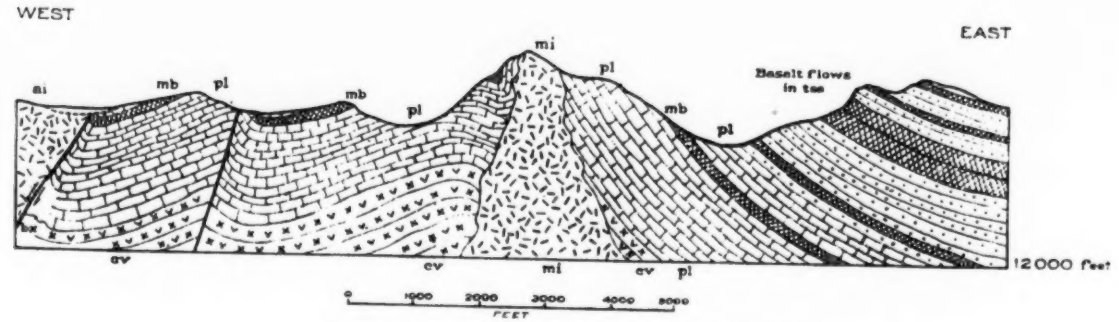

FIGURE 5.—*Generalized geologic Section near Morococha*

The formation extends into the Morococha district, where it forms Cajoncillo ridge, and is named from the Santa Catalina shrine, which consecrates a high pass flanked by the volcanic rocks (see figure 5). Within the area mapped geologically near Morococha the rock is so intensely silicified and altered by mineralization that identification from the hand specimen is almost impossible, but from a study of thin-sections the commonest member appears to be an andesitic tuff (fine fragments of andesite set in a matrix of volcanic dust).

It is likely, however, that detailed study of the great section of volcanic rocks exposed in the cliffs south of Yauli would reveal several other varieties, but all seen so far appear to be quartz-free and of intermediate type.

The volcanics near Yauli are considered by Steinmann to be members of a widespread formation which he calls "Mesozoica en facies porphyritica" and places at the bottom of the Mesozoic sediments.[8] Its age is said to have been determined from fossils found in limestones interstratified with similar pyroclastics in other parts of Peru. No limestone has been observed in the Catalina volcanics in the region with which we are familiar, but the position of the formation in the geologic column does not disagree with the age Steinmann assigns to it. It should be noted, however, that another series of volcanic rocks of similar appearance but of clearly later age is also included by Steinmann in his "facies porphyritica," which makes the limits of his group very indefinite. Considerable confusion will be avoided if his term is limited to volcanic rocks at the same horizon as the Catalina or Yauli formation.

The volcanic rocks of this formation occur at intervals for some distance to the north of Oroya along the valley of the Mantaro, but apparently die out before the sediments of the Mitu formation commence. Their relation to the Mitu formation is not definitely known, but the complete lack of pebbles of volcanic material in the Mitu sediments suggests that the volcanic rocks are of later age. The formation is definitely older than limestone of Lias age and may be placed provisionally at the top of the Carboniferous.

The name Yauli volcanics is proposed as a regional term for this earliest formation of volcanic rocks.

MESOZOIC SEDIMENTS

General.—The rolling hills of the plateau region, and in part the lofty ridges of the western range in this section of the Andes, have been carved chiefly from limestone and sandstone of Mesozoic age. The lower

[8] Op. cit., p. 16.

members, ranging from Triassic to Jurassic (Lias), are generally limestone. They are succeeded by a thick and persistent sandstone or quartzite with associated shales and coal measures of Comanchian age. The sandstone in turn grades into a thick series of overlying limestones and shales, which, with abundant fossiliferous horizons, have been definitely shown to range from Aptian (Comanchian) to Senonian (Cretaceous) in age. A slight structural unconformity may possibly separate the lower limestones from the sandstone, but otherwise the sediments appear conformable. The formations older than the sandstone will be discussed under the heading "Lower limestones."

Lower limestones.—The limestone underlying the thick sandstone formation of this section of the Cordillera is mostly of Jurassic age. A thin formation of Triassic limestone occurs at its base in the Cerro de Pasco region, but it is apparently of very limited extent. Throughout the greater part of the region under consideration the lower limestones contain fossils of Lias age.[9] Other Jurassic formations are missing except toward the north, near Huallanca, where beds appear which are correlated with the Portlandian of the Upper Jurassic.

The Triassic limestone at Cerro de Pasco, known as the Uliachin limestone, occurs at the base of the more extensive Jurassic limestone, which forms the ridges and basins farther east. Only a few hundred feet are exposed before the Triassic beds are cut off on the west by an extensive fault which brings them sharply against Excelsior sediments and a later limestone conglomerate. The rock is a dark, carbonaceous limestone low in magnesia. A composite sample gave the following analysis:

SiO_2	Al_2O_3	Fe	CaO	MgO
11.5 per cent	1.3	0.5	47.9	0.8 per cent

The determination of age of the formation is based on an abundant fossil originally considered to be a *Trigonia,* but later recognized by Steinmann and Bravo to be *Myophoria inæquicostata,* which is accepted as indicative of the Triassic.[10]

Near Cerro de Pasco the base of the Uliachin limestone is not shown. It does not rest conformably on "slates and sandstone," as stated by Steinmann,[11] who considers the altered sediments of the Excelsior series to be lower members of the Mesozoic formations, but is separated from

[9] According to Bravo (oral communication), the most characteristic fossils of the lower limestones (Paria and Pucará limestones of our classification) are: *Rhynchonella tetraedra* Sow., *Terebratula f. sub oroides* Roem., *Pecten alatus* v. Buch, *Arietites conybeary* Sow., and *Pentacrinus.*

[10] C. I. Lisson: Edad de los Fosiles Peruanos y Distribucion de sus depositos en la Republica. Lima, Peru, 1913, p. 16. With references.

[11] Op. cit., p. 19.

them by a fault of great magnitude. There is no evidence whatever to support Steinmann's statement that the vertical "slates and sandstones" (our Excelsior series) are of Jurassic age, and consequently the extensive overthrusts postulated by Lisson are not needed to explain the structural relations of the formations.

The Paria limestone, which conformably overlies the Triassic beds on Uliachin ridge, forms the entire eastern half of the Cerro de Pasco district and extends far to the south along the eastern side of the Junin pampa. In most places its base is not known, but to the north of Cerro de Pasco it rests on Mitu conglomerate or directly on upturned and eroded beds of the Excelsior series, apparently without intervening sediments of Triassic age. More careful search may find them in more places than known at present. The formation attains a thickness of at least 4,000 feet. The lower beds are dolomitic. A composite sample analyzed as follows:

SiO_2	Al_2O_3	Fe	CaO	MgO
10.5 per cent	0.7	1.3	36.6	9.6 per cent

The fairly abundant fossils are considered indicative of the Lower Jurassic (Lias).

From a structural standpoint, the best defined member of the lower limestones is the formation in the Goyllarisquisga region which outcrops persistently between the Mitu conglomerate and the overlying coal-bearing sandstone. It is a massively bedded buff to light gray rock, varying from 100 to 1,000 feet in thickness. Fossils are not abundant, but a few indicating Lias age have been found.[12] In our work the formation has been named the Pucará limestone, from the prominent exposures at the mouth of the new Pucará tunnel below Goyllarisquisga.

In the Jatunhuasi region, 40 miles south of Oroya, a similar limestone underlies the coal-bearing sandstone. Very few fossils have been found in it, but Dueñas states that it is of Lias age.[13] Its usual thickness is about 2,300 feet. Locally it is termed the Condorsinga limestone.

In the Morococha district the lower limestone (known as the Potosi limestone) is probably to be correlated with the Pucará and Paria formations (figure 5). It underlies a thick series of sandstone and shale similar to the rocks in the district mentioned above, and Jurassic (Lias) fossils have been found in it.[14]

[12] E. I. Dueñas: La Cuenca Carbonifera Setentrional Lima-Junin. Bol. del Cuerpo de Ingenieros del Perú, No. 97, 1919, p. 205.

[13] Unpublished report, quoted in the Anales del Congreso de la Industria Minera. Tomo IV, Lima, 1921, p. 275.

[14] C. I. Lisson: Op. cit., p. 20.

The faunal and lithographic similarity between the lower limestones at Cerro de Pasco, Goyllarisquisga, Jatunhuasi, Morococha, and elsewhere is so definite that they may safely be considered the same formation. The name Pucará limestone is suggested as a regional term.

Goyllarisquisga-Jatunhuasi sandstone.—The thick formation of sandstones and shales with which the coal of the Peruvian Cordillera is associated forms a prominent division between the Mesozoic limestones. It is a persistent formation and may be traced for great distances, although notably variable in thickness and prominence. The rock is generally composed of white quartz sand, medium grained for the most part, but with some thin beds with quartz and chert pebbles coarse enough to allow the rock to be considered a conglomerate. The sandstone is nearly everywhere strikingly cross-bedded. Thick beds of red and black shale occur intercalated with the sandstone at several horizons. Basalt flows (now amygdaloids) or diabase sills are also fairly common members of the formation. Some indication of coal measures (fire clay, clay, carbonaceous shale, or oil shale) can nearly always be found, but not at a constant horizon. The coal itself is by no means a persistent feature, but generally appears in isolated lenses which grade into black shale on the margins.[15] Fossils are not abundant, but sufficient have been found to establish the age of the coal as Comanchian.[16] Fragments of wood converted into black coal are not uncommon throughout the sandstone.

In the Goyllarisquisga district the formation ranges from 2,100 to 2,800 feet in thickness and may be divided into the following members:

	Feet
Calcareous sandstone	600
Chontas sandstone	900
Bolognesi beds	500 to 600
Upper Coal Measures	10 to 250
Morocata sandstone	100 to 400
Lower Coal Measures	50 to 150
Basal conglomerate	5 to 30

[15] The exceedingly large estimates of coal reserves in Peru made by several writers are open to doubt, for they are based on assumptions of continuity which detailed study would probably fail to confirm. The occurrence of the coal in local basins or lenses of limited size has been emphasized in a recent paper by J. A. Broggi (Caracter Sensiblemente Lenticular de los Depositos de Carbon de Goyllarisquisga; Archivos de la Asociación Peruana para el Progreso de la Ciencia, Tomo II, Fasciulo I).

[16] C. I. Lisson: Edad de los Fosiles Peruanos y Distribucion de sus Depositos en la Republica. Lima, Peru, 1913, p. 30.

E. I. Dueñas: La Cuenca Carbonifera Setentrional Lima-Junin. Bol. del Cuerpo de Ingenieros del Peru, No. 97, 1919, p. 208. The following fossils are mentioned: *Weichselia mentelli* (Brongn.) Seward, *Brachyphyllum pompockii* Salfeld, *Equisetites peruanus* R. Nauman, *Otozamites*, which are considered by the above-cited authors to indicate the Wealden horizon at the base of the Valanginian.

The several members vary considerably in thickness, even within rather short distances, and the figures stated above, although based on exact measurements, are merely indicative of average relations (figure 4).

The lower coal measures are the most persistent throughout the region, but generally contain only thin or dirty coal in rather small lenses. They rest on a bed of fine to medium grained conglomerate composed of pebbles of white quartz and gray chert in white quartz sand. The quartz pebbles were probably derived from the abundant quartz lenses in the Excelsior beds and in the older schists, but the chert could have come only from the concretions abundant in the underlying limestone, which indicates an interval of mild erosion at least between the Pucará and sandstone formations.

The thick coal deposit which supports the large mine of the Cerro de Pasco Copper Corporation at Goyllarisquisga is in the upper series of clays and oil shales. Except within a few miles of the principal mine, however, this horizon is barren. The coal is sub-bituminous in grade, of coking quality, but high in ash.

The Bolognesi beds consist of red sandstone and shale, which are strongly contrasted with the light gray of the massive Morocata and Chontas sandstones which lie beneath and above them. Near Goyllarisquisga three lava flows are interbedded with the sediments of the Bolognesi member, 230 to 290 feet above the upper coal measures. The lowest flow is of rather limited extent, as if it had been confined to a shallow valley. The succeeding lavas, which follow on the first without intervening sediments, occupy successively wider areas and apparently spread over the low barriers which confined the earlier flow and extended over the sandy plain for great distances. The flows range from 30 to 100 feet in thickness.

In the Oyón district, which lies in a zone of intense folding and overthrust faulting on the Pacific side of the Cordillera, 40 miles west of Cerro de Pasco, the sandstone has been converted into a resistant quartzite and the accompanying coal changed in grade from sub-bituminous to semi-bituminous or even semi-anthracite. The formation occurs near the base of the quartzite, but the structure is so complicated that definite correlation of horizons with those at Goyllarisquisga and Jatunhuasi is difficult. The major structure is an anticline with the coal pinched into a confusion of minor folds in its core. Toward the northwest the anticline breaks and becomes an overthrust fault along the coal measures themselves, which appear to have served as a lubricant for the mighty movements of the overriding masses of rigid quartzite. Blocks of the coal measures are bent and dragged over, like the crest of a break-

ing wave, with the coal beds thickened to irregular bunches or squeezed to thin partings between the more competent wall rock (figure 6). The quartzie, with coal at intervals, continues far into northern Peru, where in most deposits the coal approaches an anthracite in composition. The same belt also extends 30 miles or more south from Oyón into the Checras region, where some lenses of low-grade anthracite have been mined on a small scale. On Oyón maps[17] the rock has been named the Conocepata quartzite. It is without doubt to be correlated with the Goyllarisquisga-Jatunhuasi sandstone.

The sandstone occurs at intervals in the high country of pampas and rolling hills between Goyllarisquisga and Oroya, but the formation is generally rather thin and no coal is known. Near Morococha, where it is termed the

FIGURE 6.—*Generalized Section through Suquiracha, Oyón Coal Field*

[17] Private reports.

Toribo sandstone, it contains numerous flows of basalt and grades without marked contact into thin-bedded limestones and shales which overlie it (see figure 5).

South of Oroya the sandstone becomes more prominent, and in the Jatunhuasi district again contains coal deposits, possibly of commercial importance. The formation there attains a thickness of about 2,850 feet. The horizon of the Goyllarisquisga coal, however, is occupied by a thin deposit of limestone overlain by a band of red shale, the whole amounting to a thickness of about 820 feet. These beds occur in the sandstone about 720 feet above its base. The coal and associated clays and shale occur at a higher horizon, only 250 feet below the contact of the sandstone and the upper limestone. The coal measures themselves are thinner than in the other fields, but the coal, though dangerously near the limit of practical mining thickness, is fairly persistent. The beds are folded into a gentle syncline in the principal part of the field, but more complicated structures are not far distant on the flanks of the area (figure 7). The coal is similar in grade to that of Goyllarisquisga. No lava flows have been found in the Jatunhuasi district, but diabase intrusions (chiefly sills), which show an annoying affinity for the coal horizon, are common features. The zone of sandstone, with thin coal at intervals, continues many miles to the southeast, well into the Department of Huancavelica.

Machay limestone.—The thick limestones and shales into which the coal-bearing sandstone or quartzite grades contain the most definitely determined horizons in central and northern Peru. The formation is widespread and forms broad areas in many parts of the plateau country, and in some regions, particularly in the Jatunhuasi district, the highest ridges of the western Cordillera are carved from it.

In the Goyllarisquisga district, where the formation was first encountered in the course of our work and was termed the Machay limestone, from a line of high cliffs with many small caves known by that name, it is limited by an unconformity with overlying conglomerates and only a partial thickness can be seen. In the Oyón and Jatunhuasi regions much greater thicknesses exist. No exact measurements have been made, but it is probable that the formation as a whole exceeds 2,000 feet. The beds are well exposed near Oroya, where they plunge into the anticlinal valley of the Mantaro River.

On faunal evidence, the formation may be divided into two distinct members. The lower one, which may be termed the Chulec member, from a prominent exposure near Oroya, consists of thin-bedded, light-gray limestone, weathering white, with minor beds of sandy shale. It

contains abundant fossils indicative of Aptian age (Fredericksburg of the Comanchian). The upper member, known as the Pariatambo, from one of its best exposures, about 10 miles southwest of Oroya, is thicker. The limestone is usually darker than the lower beds and almost everywhere yields a pronounced odor of organic matter or petroleum, when freshly broken. The beds are noted for the fine specimens of ammonites which have been collected from them. The abundant fossils correlate the deposits with the Albian-Vraconian of western Europe (Washita of the Comanchian in the United States).[18]

Jumasha limestone. — The youngest formations of the Mesozoic is a uniform light gray limestone, generally more massively bedded than the Machay formation. It is prominently developed in the cliffs above Jumasha on Lake Punrun and along the crest of the Cordillera from the Jatun

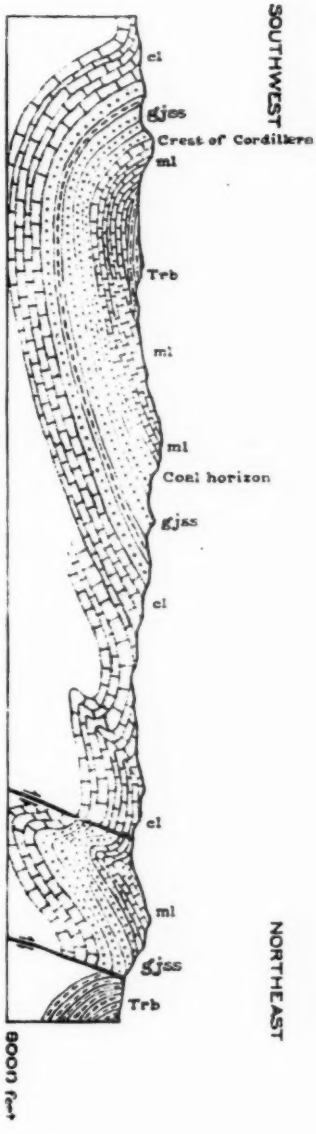

FIGURE 7.—*Sketch Section through Jatunhuasi Coal Field*

[18] C. I. Lisson: Op. cit., pp. 31-58. E. I. Dueñas: Op. cit., pp. 210-213. According to Bravo (oral communication), the fossils most typical of the Chulec limestone are the following: *Vola 5 costata* Sow. sp., *Knemiceras attenuatum* Hyatt, *Enallaster* cf. *Peruanus* Gabb, *Holectypus* sp. The most typical of the Pariatambo limestone are the following: *Schoenbachia peruanum* v. Buch. sp., *Mortoniceras rentanillensis* Gabb. sp., *Acanthoceras lyelli* Leym. sp. Echinoderms are lacking.

Chacua pass for many miles to the north.[19] In these occurrences it is bounded by faults and its relations to the Machay beds are obscured, but in the Oyón district and elsewhere it may be seen to rest conformably on them. The formation attains a thickness of at least 1,500 feet and possibly considerably more.

In the Jumasha Valley it is overlain by red shales and sandstone, probably of Tertiary age.

An extensive fauna has been described and the formation is definitely correlated with the Senonian of western Europe (Cretaceous).[20]

TERTIARY (?) SEDIMENTS

General.—An unconformity representing a break of great magnitude separates the sediments which succeed the Machay and Jumasha limestones from all preceding formations. The later deposits rest not only on various horizons of the Mesozoic sediments, but even directly on the upturned edges of the Excelsior beds over large areas where all intervening sediments have disappeared. Where this relationship can be seen, proving a great break between the Cretaceous sediments and the succeeding rocks, it is justifiable, even without paleontological evidence, to consider the later deposits to be of Tertiary age. In many areas, however, the younger sediments are less strikingly separated from the Machay formation, and their assignment to the Tertiary is less certain, being based only on superposition on Cretaceous rocks and on their lithologic similarity to the formations that lie above more definite unconformities. There is an irritating lack of fossils in all districts where these beds have been studied.

The formation most commonly consists of limestone conglomerate, white limestone, and quartzite conglomerate members interbedded with very thick and more uniform deposits of red sandstone, red shale, and red calcareous shale. The limestone conglomerate occurs as a basal formation in some districts, but is most prominently developed at higher horizons. Several layers of quartzite conglomerate ranging from 10 to 600 feet in thickness occur in the red sediments, where they are useful horizon markers for structural studies. The limestone is generally in thin white beds, in striking contrast to the red rocks which flank it. The sediments are overlain by a thick series of volcanic rocks, mostly pyroclastics, which will be discussed as a distinct, though related, formation.

[19] E. I. Dueñas: Op. cit., p. 213.

[20] C. I. Lisson: Op. cit., pp. 48-58. The fossils most typical of the Jumasha limestone, according to Bravo (oral communication), are the following: *Tissotia* cf. *fourneli* (Boyle) Thom. et Per., *Hemiaster fourneli* Desh., *Ostrea nicaisei* Coqu.

Pocobamba formation.—In the Goyllarisquisga district, 20 miles or so northwest of Cerro de Pasco, the Tertiary (?) sediments are thick and exhibit all phases of the formation. The lowest member is a thin bed of limestone conglomerate which was deposited unconformably on both Machay limestone and Goyllarisquisga-Jatunhuasi sandstone (see figure 4). On it rests a succession of red shales and sandstones, with two or more thin but prominent beds of conglomerate known as the Red Cut member. The conglomerates are well cemented gravels composed of pebbles of quartzite, chert, and limestone. The siliceous pebbles generally outnumber the limestone by about four to one. Pebbles of igneous material are very uncommon. The matrix is a siliceous sand cemented by lime and iron oxides. The pebbles are well rounded and commonly range from 3 to 6 inches in maximum diameter. The reddish sediments are succeeded by a white limestone known as the White Cut member. It in turn is overlain by more shale and sandstone of varying thickness, which is followed by a very thick and widespread deposit of limestone conglomerate. The maximum thickness of the entire formation is probably well over 2,500 feet. Where mapped, near Goyllarisquisga, the lower limestone conglomerate and the Red Cut member amount to 600 feet.

The Shuco limestone conglomerate, which is a prominent rock in the Cerro de Pasco district, appears to be an upper member of the thicker Pocobamba formation. Near Cerro de Pasco the underlying red sandstones, shales, and lower conglomerate of the Goyllarisquisga district are missing, and the upper limestone conglomerate rests directly on the upturned edges of Excelsior beds and covers smaller areas of Paria limestone (see figure 3). The rock is composed of subangular blocks of limestone ranging from the coarseness of fine gravel to boulders 10 to 15 feet in diameter. The matrix of finer limestone sand is bound together by a lime cement, generally with enough iron to give the whole rock, particularly when seen from a distance, a light reddish tint. Fossils are not uncommon in the blocks of Mesozoic limestone from which the bulk of the deposit is derived, but none indicative of the age of the deposit itself are known. Near Cerro de Pasco the conglomerate residues, which cap two ridges, are about 250 feet thick. Farther south the Shuco member is overlain by further deposits of red shale and a thin white to light-gray limestone, known as the Calera limestone, which in turn appears to have been buried under still later thick accumulations of limestone conglomerate.

Red sandstones and shales, undoubtedly of the same age as the sediments of the Pocobamba formation, are prominent in the Huaron district, 20 miles south of Cerro de Pasco, and the formation continues to

appear at frequent intervals for long distances to the southeast along a zone parallel to the crest of the Cordillera. It has not been studied in detail in the course of our work, except near Casapalca, where the red beds form the principal sediments of that mineralized region.

Casapalca formation.—From the line of the Central Railroad for 30 miles or more to the southeast the crest of the Andes is formed of red sedimentary rocks similar to those previously described or of volcanic rocks associated with them. The base of the formation is generally obscure, except between Ticlio and the Yauli Valley, where the red beds rest on limestone of Upper Cretaceous age (probably Machay limestone). In the Casapalca[21] district the formation consists of at least 4,000 feet of light red shales and shaly limestone, with two or more horizons of thin beds of quartzite conglomerate and white limestone. The quartzite conglomerate is composed of well-rounded pebbles, somewhat larger than hens' eggs, on the average, with a scattering of limestone pebbles, set in a gray to slightly red cemented sand. The formation, as seen in the Viscas Valley and in the Yauli Valley, to the east, is thicker (estimated roughly to be at least 6,000 feet). It is rather noticeably divided by a zone of conglomerate and thin limestone beds. The sandstone and shale below this horizon are a lighter red than the sediments above it. This division can also be detected near Ticlio. The highest sediments near Casapalca (though probably not the top of the formation) consist of a group of limestone and conglomerate beds known as the Carmen member, which forms an unusually persistent horizon. These sediments are succeeded by pyroclastic rocks or igneous breccias. Fifteen miles or more southeast of Casapalca, between the drainage of the Rio Blanco and the Yauli River, the top of the formation is likewise formed of a similar quartzite conglomerate, but in much greater thickness (at least 1,500 feet). The conglomerate there is also succeeded, apparently, conformably by volcanic beds (figure 8).

The sediments near Casapalca are shown on Steinmann's section[22] as Jurassic and Cretaceous shales, but the formation is not described or even mentioned in the text and no evidence whatever is presented in support of this improbable conclusion.

Remnants of red beds, preserved at intervals in three synclinal zones, occur in the region southeast and south of Oroya. The rocks are similar to those described. An infolded basin of red shale and shaly limestone parallels the Mantaro River two to three miles to the southwest from

[21] The work of Mr. H. E. McKinstry, now in progress, on the geology of the Casapalca district deserves particular mention.

[22] Op. cit., attached section.

Huari to Pachacayo and beyond. Many flat-topped ridges are capped by banks of quartzite gravel, most probably derived from the disintegration of quartzite conglomerate members. A zone of red beds, with some very thick conglomerates at the north end, extends from the vicinity of the Hacienda Cochas southeast into the Consac and Yanacocha basins, faulted down against the great block of Mesozoic sediments which forms the Jatunhuasi district to the southwest. A broad basin of red beds lies with slight unconformity on the Machay limestone in the syncline in the heart of the Jatunhuasi coal field[23] (figure 7). The formation continues at intervals well into the Department of Huancavelica.

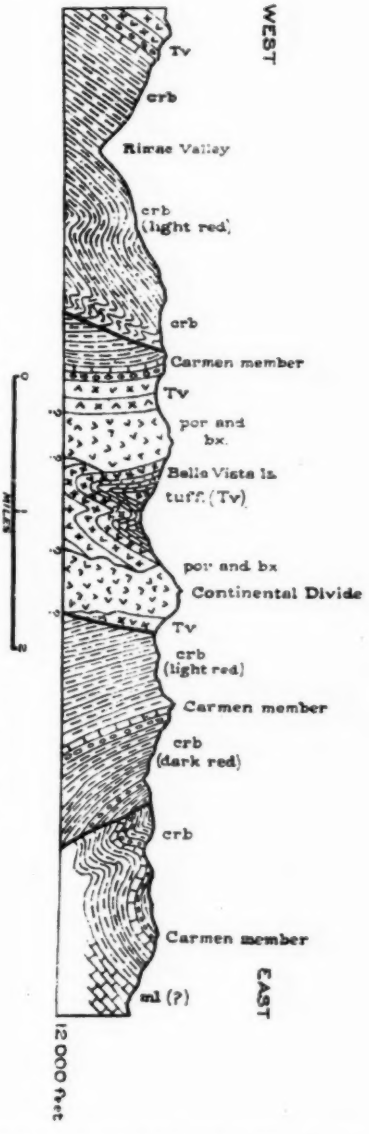

FIGURE 8.—*Generalized Section through the Casapalca District*

An acceptable determination of the age of these beds is very necessary for a proper understanding of the stratigraphy of this portion of the Cordillera. Careful search may lead to the discovery of some fossiliferous horizon, but to date no paleontologic evidence of a final nature has been found. On structural grounds it seems certain that the sediments are later than the Upper Cretaceous, and there is good reason to believe that they are sepa-

[23] Dueñas suggests a Tertiary age for similar beds in the Jatunhuasi region. Anales del Congreso Nacional de la Industria Minera. Tomo IV, Lima, Peru, 1921, p. 276.

rated from it by an interval of great magnitude. As has been stated, the proof of the unconformity in the Cerro de Pasco and Goyllarisquisga districts is sufficiently definite to justify the assignment of the younger conglomerates and red beds to the Tertiary, and the similarity between these sediments and those in the Casapalca region, and in other places where the unconformity is less positively shown, is so striking that it is reasonable to consider them all as parts of one great formation. The existence of pebbles of altered Cretaceous rocks in the conglomerates is a further indication of the time interval separating the red beds from the preceding sediments. The only adequate source of quartzite pebbles and boulders, as far as known, is the quartzite of Cretaceous age, and its existence at the time of the deposition of the conglomerate indicates a period between the two formations sufficiently great to allow the metamorphism of incoherent sandstone into resistant quartzite. It is admitted that these arguments do not constitute a final proof, but it is believed that they present a strong case for assigning a Tertiary age to the red beds of the Casapalca and related formations. More definite determination must await the results of patient research and study of the scanty fossil evidence.

TERTIARY (?) VOLCANICS

General.—An extensive group of volcanic rocks, mostly pyroclastics with subordinate flows, rests on the sediments described in the preceding section. From partial studies it appears that the chief mass of the rock ranges from soda trachyte to andesite in composition, but dacitic (and probably rhyolitic) members are of importance in some districts.

Lourdes tuff and Rumiallana agglomerate.—In the Cerro de Pasco district two formations are confidently assigned to the later volcanic group. The earlier rock, known as the Lourdes tuff, is definitely of pyroclastic origin. In its deeper portions (the base is not exposed) it is practically an igneous breccia. Passing upward, it becomes of finer fragmental texture, and, finally, with gradual increase of foreign material at the expense of igneous fragments, it passes into a roughly bedded, heterogeneous deposit known as the Rumiallana agglomerate.

The Lourdes tuff outcrops in a crescent-shaped area which possibly outlines part of the original vent, but it is so modified by faults on the east and south, which have dropped the tuff against Paria limestone and sediments of the Excelsior series, that no positive conclusions on this point are possible. It is a massive rock, without bedding, and greatly resembles a porphyry or fine-grained plutonic rock when seen on a fresh surface. Where weathered, the fragmental nature becomes more appar-

ent, and angular grains and blocks (up to 6 inches or more in diameter) of porphyry become easily distinguished from the matrix of dust and finer fragments of similar material which cements them. With depth, the blocks of massive porphyry become larger, and it is likely that the rock finally passes into a porphyry, not disrupted, but merely somewhat shattered, by the explosions which formed the tuff. On the northern edge of the district the tuff and breccia have a slightly purplish, light gray tint, but closer to the mineralization the rock is bleached to a uniform white.

Under the microscope the Lourdes tuff may be seen to be composed of fragments of quartz and feldspar (.4 to .5 millimeter in maximum diameter), with a minor amount of mica set in a matrix composed of very much finer grains of similar material. All the fragments, but particularly the quartz, are notably angular. Many quartz grains, however, still show remnants of an original rounded and even embayed outline, which is enough to suggest that they were derived from phenocrystic material. The feldspar is probably plagioclase, but the thin-sections at hand are from such altered material that almost all minerals, except quartz, are converted to fine mats of sericite, with minor amounts of epidote, chlorite, and calcite. A little apatite occurs in fairly sharp grains. Small fragments (0.5 to 2.0 centimeters in diameter) of foreign rock are abundant. The commonest is composed of fine interlocking quartz grains and is probably a quartzite or a silicified sediment from the Excelsior series. Porphyry fragments of variable sizes also occur, and toward the top of the formation dark, dense bits of altered shale or phyllite from the Excelsior series become more and more abundant.

The Rumiallana agglomerate appears first as finely banded layers of darker material in the Lourdes tuff. Passing upward, the tuff gradually changes from white to gray in color, the bedding, which is first seen as fine laminations, becomes coarser, and, finally—with the appearance of boulders of porphyry, Lourdes tuff and limestone, and, most abundant of all, fragments of altered shale, quartzite, or phyllite from the Excelsior series—the rock becomes a heterogeneous mixture which is most properly described as an agglomerate. A slight amount of rounding due to water action can be detected in the coarser material and cross-bedding may be seen in a few exposures. Under the microscope the matrix is not unlike the Lourdes tuff, except that even the finer quartz grains are more heterogeneous in size, and that there is a greater proportion of fragments of altered shale, which gives the rock a darker color.

The Lourdes tuff was probably formed from products of volcanic explosions settling and accumulating in or not far from the vent. The

Rumiallana agglomerate, formed under the succeeding conditions, appears to be the more extensive and more heterogeneous deposit resulting from the washing of the dust-covered country by torrential streams. The relations of the tuff and agglomerate to the local Tertiary sediments is not definitely shown. The pyroclastic rocks rest largely on Excelsior sediments and are covered by no later deposits, though cut by intrusives. The neighboring limestone conglomerate, which is near the top of the extensive Pocobamba formation (Tertiary?) of the Goyllarisquisga district, contains no pebbles or even sand derived from the volcanic rocks. It may be safely assumed that they are later than the conglomerate and are to be correlated with the Tertiary volcanics above the red beds in other parts of the region.

Rock Forest dacite tuff.—In the region northwest of the Junin pampa an extensive area is covered with a rather flat-lying deposit of tuff, which is probably to be correlated with the Lourdes and Rumiallana formations of the Cerro de Pasco district. The rock is composed of abundant angular or subangular fragments of quartz and basic oligoclase set in a fine matrix of similar material and fragments of volcanic glass. The rock resembles a dacite in mineral composition. Throughout the entire region the rock is slightly silicified along intersecting joints, which, by causing a peculiar sort of differential weathering, has produced an area of fantastic pinnacles and spires, known among the English-speaking population as the Rock Forest. The formation dips toward the northeast and rests conformably on Tertiary (?) red beds.

Casapalca volcanics.—The most interesting development of the Tertiary volcanic rocks is in the Casapalca district. There a thick series of mud-flows, lava-flows and tuffs, and igneous breccias of uncertain origin succeeds the red beds of the Casapalca formation. The whole formation is complicated by intrusive material in sills or small laccoliths, dikes, and small stocks. The lowest member of the volcanics is generally an agglomerate composed of pebbles of dense porphyry or porphyries (2 inches to 18 inches in diameter) and in some places rounded pebbles (of similar size) of limestone and other sediments set in a matrix of finer igneous fragmental material and dust. The bed of this "igneous conglomerate" is about 150 feet thick and fairly persistent throughout the district. It is probably the result of a mud-flow, which has picked up extensive floodplain gravels in its course. The overlying rock is generally a similar agglomerate, but without the limestone and more obviously volcanic in origin. It attains a thickness of around 500 feet or more in parts of the district and forms a prominent member of the series, easily recognized, even from a distance, by its purplish red color.[24]

The rock which apparently succeeds the "purple volcanics" is an igneous breccia composed of angular fragments of gray to brownish red soda trachyte and andesite set in an igneous cement of similar material. Whether or not this rock forms portions of thick flows, brecciated by their movements when partially solidified, or marginal portions of explosive vents, still remains to be determined. Most thin-sections show the fragments or blocks which compose the rock to be porphyries with phenocrysts of albite or albite-oligoclase and hornblende set in a trachytic groundmass of similar feldspars and orthoclase. Orthoclase phenocrysts are not uncommon, but are generally subordinate. More basic varieties contain andesine phenocrysts in a groundmass of fine laths of oligoclase.

A thin-bedded, siliceous limestone, known as the Bella Vista limestone, is interbedded with the volcanic rocks near the top of the formation exposed near Casapalca. No fossils have been found in it, although they have been diligently sought in several places. The limestone is overlain by several thousand feet of massively bedded volcanic rocks with some thin sills, which become of great prominence to the west of the Casapalca district, particularly along the canyon of the Rimac River near its junction with the Rio Blanco, where a series of magnificent cliffs have been carved from them. These upper members of the Tertiary volcanic rocks have received little study to date, but in a general way they appear like the lower beds, both in textures and composition.

A certain amount of massive intrusive rock of fine-grained plutonic texture is generally associated with these breccias and may represent the massive intrusive phase of which the breccias are explosion products. The intrusive masses are elongated parallel to the prevailing structure, but are of small area and are most probably apically truncated stocks. It is probable that these intrusives must have been fairly close to the surface, for the portions now exposed are very near the top of the known sedimentary column. In fact, it is likely that their only mantle was the unconsolidated fragmental volcanic material blown and washed over the district in the first phases of the same igneous period.

TERTIARY INTRUSIVES

General.—The intrusive stocks near Casapalca are merely small members of a long line of similar igneous masses which occur in rough zones parallel to the trend of the regional structure. The rocks vary from quartz diorite and quartz monzonite to diorites and syenites in composi-

[24] With the completion of the detailed geologic map of Casapalca now being prepared by the Geological Department, more definite subdivision of these formations will be made and the generalizations stated in this paper may need some modification.—D. H. McL.

tion, and from medium-grained plutonic textures to porphyritic textures of various grain. The major intrusions are nearly always in the form of stocks. A greater variety of rocks is found in the small dikes, sills, or irregular laccoliths in the neighborhood of the larger intrusives. No masses of igneous rock sufficiently large to be classed as batholiths are known in the high country in this part of the Andes. The dioritic batholiths of Tertiary age, which flank the range on the Pacific side, do not extend much farther east than the intermediate slopes. Areas of granite and gneissic rocks occur in the eastern range, but it is certain that they are pre-Tertiary and likely that they are in part pre-Mesozoic.

Cerro quartz monzonite porphyry.—The most interesting intrusion from an economic standpoint is the stock of quartz monzonite porphyry near Cerro de Pasco, which is generally regarded as the source of the ore deposits of that famous district. The rock occurs in an irregular cross-cutting mass about a mile in its longest diameter. It intrudes sediments of the Excelsior series, the Lourdes tuff, and Rumiallana agglomerate and Shuco limestone conglomerate, but does not come in contact with the Mesozoic sediments. The rock is a light gray porphyry with large phenocrysts of orthoclase (1 to 3 centimeters long) and small grains of quartz, plagioclase, and biotite set in a dense groundmass. The plagioclase is commonly in zoned crystals ranging from andesine to basic oligoclase. The quartz phenocrysts are rounded and many are deeply embayed by the groundmass. The groundmass is microcrystalline, with orthoclase, quartz, and a little plagioclase as chief constituents. Apatite, titanite, zircon, and magnetite are accessory, the former almost phenocrystic.[25]

The rock is very generally pyritized, but contains no mineral deposits of importance. The contacts are obscured by swamps and pampas, for the most part, but where exposed show no development of metamorphic minerals. The idea of genetic association of the ores of the district with this rock is a matter of inference from other well-known examples rather than a direct deduction from local observations.

At Huaron, later red sandstones and shaly limestones are cut by a small stock of quartz monzonite porphyry. An examination of thin-sections shows the rock to contain basic oligoclase set in a very fine-grained groundmass of orthoclase with very subordinate quartz. Some development of contact metamorphic minerals occurs around the margin of the intrusive rock, and veins with the characteristic ore minerals of the province cut both sediments and igneous rock.

[25] This rock and the Morococha intrusive were first determined to be quartz monzonite by Dr. Waldemar Lindgren in 1916, from studies of thin-sections furnished by Mr. J. M. Boutwell. Subsequent study of additional material has confirmed this determination.

Anticona and Morococha intrusives.—West of Morococha a large stock of fine to medium grained plutonic rock and associated porphyries cuts the Casapalca formation and the Mesozoic sediments. The main body of the stock, which forms the lofty Yanasinga ridge, is a greenish gray rock, generally porphyritic. A study of thin-sections reveals considerable variation in its composition, but the dominant phase appears to be a granodiorite porphyry composed of phenocrysts of quartz, plagioclase (ranging from andesine to acid labradorite), and biotite in a fine-grained to dense groundmass of quartz and subordinate orthoclase with numerous fine flakes of biotite or shreddy amphibole. It is intruded (particularly on the eastern side near Morococha) by numerous smaller and very irregular masses of a lighter quartz monzonite and corresponding porphyry. The later intrusions are very similar to the earlier rock, but contain less dark constituents, more quartz, and slightly more orthoclase. In the plutonic phase the rock is composed of andesine, quartz, and orthoclase, with a subordinate amount of biotite and a little hornblende. The porphyritic phase contains the andesine, quartz, and biotite phenocrysts (with rarely a crystal of orthoclase) set in a groundmass of orthoclase with subordinate quartz. The earlier rock has been called Anticona intrusive; the later, the Morococha intrusive. Mineralization in the district is probably related to both rocks, but that associated with the latter is by far the more important.

REGIONAL STRUCTURE

At least three and possibly four periods of important deformation have left their record in the structures of the region. The pre-Mesozoic deformations were probably the most intense, but little is known of them except that they were widespread and produced folded and faulted structures of far greater intricacy than those in any succeeding period.

The folding and faulting at the close of the Cretaceous and the later movements which affected the Tertiary (?) red beds have been mentioned on previous pages. A final period of block-faulting probably accompanied the latest uplifts of the region.

From these deformations there has resulted a series of dominant folds and strike faults (mostly overthrusts) with northwest trend (north 20 degrees to 45 degrees west, generally). In the plateau country the folds are fairly open and the beds are bent in smooth regular curves. As the axis of the western range is approached, the intensity of the deformation increases. Folds become tighter and overthrusts become more prominent. Cross-breaks and warping folds, causing pitching anticlines or synclines, are common, but are usually local features and explainable as

necessary adjustments to irregular stresses caused by differential yielding on the dominant northwesterly folds and overthrusts.

Areas in which the Excelsior series reaches the surface are most common in the eastern half of the plateau region and on the eastern ranges. Toward the west the Mesozoic limestones dominate until they, in turn, disappear under or against the Tertiary (?) red beds or related volcanics. These later formations form a prominent belt, which extends along the axis of the range from the Huaron district to the county far south of the area under discussion. The belt of volcanic rocks usually continues west until cut off by the diorite batholith of the lower hills. In general, the greatest elevation of the crust seems to have taken place in the eastern half of the Cordillera, and the younger formations are broken and crumpled in a zone along its western side, but broader regional studies are needed to confirm these generalizations.

GEOLOGIC HISTORY

Pre-Mesozoic era.—The long period of sedimentation in which the deposits of the Excelsior formation were formed is the oldest event recorded by the geology of the region, if the little-known eastern schists and gneisses are neglected. It marked the beginning of a great cycle, involving intense folding, incipient regional metamorphism, and peneplanation, which was completed and the rocks left very much as they are today before the region was buried beneath the Mesozoic (or possibly in part earlier) sediments. A good record of the region at the close of the cycle is preserved in the Mitu formation. It is probable that very little massive limestone or igneous rock outcropped on the old surface at the end of Excelsior time, for the gravels from which the conglomerate was derived were almost entirely composed of subangular fragments of schist, phyllite, or imperfect slate and vein quartz. The surface was probably of low relief, with broad valleys bordered with gently rolling country, from which the material of the Mitu formation was derived and deposited only as an intermittent blanket, probably thickest along the lines of old valleys and lacking over the higher ground. There is no evidence of a period of folding and subsequent erosion between the time of the deposition of the Mitu beds and the succeeding limestones. In parts of the region eruptions of explosive nature took place and buried great areas of the old Excelsior surface beneath thick accumulations of volcanic fragmental material, from which were formed the beds of andesitic tuff and agglomerate of the Catalina volcanics. The pyroclastic deposits do not extend as far north as Cerro de Pasco and Goyllarisquisga, and their age relationship to the Mitu sediments is somewhat doubtful, but the

lack of pebbles derived from them in the conglomerate suggests that the volcanic formation is the younger.

Mesozoic era.—The earlier Mesozoic limestones indicate a period of widespread marine submergence with deposition on the even surface of Excelsior schists and sediments of Mitu age. The submergence lasted at least until the beginning of the Upper Cretaceous, when a decided change in conditions of deposition caused sandstone to succeed the limestones throughout the entire region. There is no pronounced structural break between the limestone and the sandstone, but a slight variation in the thickness of the limestone and the occurrence of chert and flint pebbles in the conglomerate of the base of the sandstone may indicate an intervening period of warping and mild erosion.

The thick cross-bedded deposits of clean quartz sand were probably formed in shallow waters, possibly on a low-lying coast with strong streams. Locally, deposition may have been interrupted at times by the erosion of shallow channels, as is suggested by the distribution of lava flows at Goyllarisquisga, but in general it was a period of steady accumulation. The sands were at intervals buried beneath thick beds of muds and clays, laid down probably in marshes or shallow estuaries, which may have resulted from local subsidence. Here and there vegetable material accumulated, from which lenses of coal were formed. The source of the material for these thick deposits of sandstones and shales must have been remote, at least beyond the limits of the area mantled by the earlier limestones, and distant enough to have all fragments of material less resistant than quartz worn to fine silt.

The deposition of the sands was brought to a close by gradual regional subsidence, which resulted first in the formation of sandy limestones and shales, and finally in the deposition of a great thickness of limestone (Machay formation).

Eruptions of basaltic lavas took place at several periods during the accumulation of the Mesozoic sediments. The most extensive flows were those which spread over the broad valleys in which the sands were laid down, but in the Morococha region the first eruptions commenced during the accumulation of the earliest Mesozoic limestone (the Potosi limestone) and continued at intervals even until the deposition of the younger members of the Machay formation above the Toribio sandstone. In the Jatunhuasi district sills of diabase in the sandstone were formed during the same period of igneous activity, but apparently no surface effusions occurred.

The importance and significance of the great period of deformation and erosion which followed the deposition of the Machay formation has

been discussed at length on previous pages. At that time, the close of the Upper Cretaceous, the dominant folds and faults of the region were initiated and received their first impulses. The rocks were bent into broad synclines and anticlines, and probably sufficient compression was developed to start movements along the fractures which later became the great overthrusts of the region. In certain zones the pressures involved were enough to cause the metamorphism of the Mesozoic sandstone to quartzite. The period of erosion which accompanied and followed these changes was of sufficient duration to remove great thicknesses of Mesozoic sediments and in some areas even to lay bare the underlying Excelsior beds.

Tertiary history.—Deposition, however, was resumed before peneplanation was attained. The limestone conglomerate, which forms an intermittent base for the sediments believed to be of Tertiary age, was probably formed from material washed into valleys from abrupt mountain canyons by torrential streams. In texture it is not unlike the heterogeneous and poorly sorted material in the great outwash fans which are now filling many valleys at the base of desert ranges in North America. The succeeding beds of red sandstone and shales and the shaly limestones, with the interbedded quartzite conglomerates, are likewise of continental (or in part shallow water) origin, but were probably developed in regions of milder topography and their thicker deposits spread over greater areas. There is no evidence of widespread marine submergence later than the Mesozoic.

The period of igneous activity which brings the record of the Tertiary to a close commenced before any marked deformation of the red beds had taken place. Explosive eruptions, breaking forth from many centers, blanketed the country with deposits of dust or with heterogeneous material distributed in mud-flows. A renewal of folding and faulting, chiefly along old lines, warped and broke the later sediments and the conformable volcanic beds into structures of great complexity. Igneous activity possibly continued without interruption throughout these changes. Some sills and small laccoliths had been formed earlier than the folding and were deformed with their inclosing sediments, but the main period of intrusive activity, to which the stocks of diorite and quartz monzonite belong, appears to have followed the deformation. The intrusives which were held by the older sediments are usually plutonic or porphyritic in texture; those which rose into the shallower red beds and volcanic formations are nearly always of dense porphyritic textures and in part or entirely brecciated, as if by explosions of viscous or semi-solidified material.

It is possible that some folding in the sediments occurred after the Tertiary intrusions. It is conceivable that the numerous stocks acted as rigid masses and remained unaltered, or were merely slightly sheared or faulted, when the plastic, thin-bedded sediments were crushed against them.

Mineralization throughout the entire region is very definitely associated with this latest period of igneous activity. Ore deposition commenced before the last deformations took place, as is clearly shown by post-mineral crushing and faulting in many deposits, but it continued after the last movements had ceased, for numerous deposits exist in which fragile textures are preserved even where the inclosing rocks show the effects of the latest stresses. The ore bodies range in type from contact metamorphic deposits with abundant minerals indicative of high temperatures to cinnabar deposits probably related to the solutions of neighboring hot springs. The ore deposits of greatest commercial importance, however, are those of intermediate to shallow type, formed in the later half of the sequence of mineralization. The dominance of enargite-famatinite among the ores of copper and of tetrahedrite-tennanite among the ores of silver is the outstanding feature of the region considered as a metallogenetic province.

Physiographic History

General

At least two ranges of mountains of considerable magnitude had been created along the axis of the Andes and had been obliterated before the present range came into existence. The mountains formed by the deformation of the Mesozoic sediments had been greatly reduced before the later conglomerates and red beds, believed to be of Tertiary age, were deposited, and ultimately by the combined processes of gradation a fairly complete leveling of the region was probably attained. A second mountain system undoubtedly resulted from the deformation of these Tertiary deposits, before and accompanying the period of igneous activity. The surface of mild relief, which finally resulted from the long erosion of this range, still survives in the present topography, and with it the physiographic history of the region may properly be opened.

The puna stage

The topography to which the folded Tertiary mountains were finally reduced hardly attained peneplanation.[26] It was a region of broad,

[26] This surface is undoubtedly to be correlated with the oldest surface of *post mature* topography recognized by Bowman in southern Peru. Op. cit., p. 185.

shallow valleys and low, rolling hills, whose profiles may now be seen in the even skyline of many ridges caught in the distant view. Extensive areas of this old surface remain in the broad highlands between the canyons which dissect the plateau country (see figure 4) and remnants of it still linger along the narrow transverse ridges which separate the steep streams descending the Pacific slope. In general, the surface truncates the complex structures of the Cordillera with indifference, except here and there, where the course of a particularly resistant stratum is marked by a hog's-back ridge, or where a mass of intrusive rock forms an isolated hill or prominent group of hills of Monadnock type. A subdued range of mountains probably followed the present Continental Divide, but averaged only 1,000 to 2,000 feet above the general level of the country. A few peaks toward the north may have been as much as 5,000 feet higher, but they were the loftiest of the region. A similar range of gentle dimensions possibly followed the line of the present eastern Andes. The main river valleys were well advanced in their erosion cycle and were achieving an independence of the structural irregularities of the country over which they flowed. The remnants of this early landscape are now at high altitudes (13,000 to 14,500 feet) and form an area of bleak, cold pasture lands, commonly termed "punas," from which the name suggested for this topographic stage was taken.

DEFORMATION OF PUNA SURFACE

The placid progress of the region toward peneplanation was at last interrupted by a series of broad uplifts which elevated the old surface, with some warping and possibly block-faulting, to altitudes ranging from 12,000 to 15,000 feet. Faulting may have taken place along parts of the western range. An abrupt escarpment, suggesting block-faulting, follows its eastern face for many miles in the section west and northwest of Cerro de Pasco, but it is by no means established, as yet, that such faulting was a general accompaniment of the uplift.

On the western side of the range the old surface was warped with a gentle slope toward the Pacific. It is obliterated by erosion before it descends much lower than 12,000 feet, and the history of the lower slopes is obscure. Their abruptness suggests faulting, but much more study in the difficult desert region of the Pacific slope will be necessary to prove it definitely.

JUNIN, CHACRA, AND CANYON STAGES

Two and possibly three stages in the uplift of the region are shown by the forms of the valleys cut by the rejuvenated streams. An early, rather

slight uplift, followed by a long period of quiescence, allowed the development of a series of broad valleys with flat gradients and gentle side slopes, some sections of which still exist in the broader interstream areas of the old topography. The broad pampa of Junin and similar high valleys were developed at this time, which may properly be called the Junin stage.

The next stage of the uplift was of more forceful character, and the stream rejuvenated by it deepened their valleys by 1,000 to 2,000 feet, but were again given time to reduce their side slopes somewhat before the last powerful phase set the streams cutting the sharp gorges in which they are confined today. The slopes of the valleys of the second stage, while still steep, are not precipitous and form benches on which hill villages have developed in many localities, especially in the valleys cut into the plateau region. These slopes, now midway in the great canyons, are extensively terraced and cultivated in numerous farms called "chacras," which suggests the name for the topographic stage that is responsible for their existence.[27] The name "canyon stage" is obviously suitable for the last deep gorges.

The master lines of drainage on the eastern side of the Continental Divide were probably well established during the development of the early surface of mild topography. Even at that time the Continental Divide very likely followed the axis of the western range. No breaches occur in it—few passes are now lower than 15,000 feet—and no stream has maintained itself across it in antecedent relations. The eastern range, on the other hand, is cut through by several great streams, which gather their waters from the eastern slope of the western range and flow into the Amazon basin through mighty valleys which suggest long-established courses.

The first uplift caught the eastern streams in wide, open valleys, which were little influenced in detail by the underlying rocks and structures. With the quickening of currents the rivers intrenched themselves along the chance courses where the rejuvenation reached them, forming gorges in hard formations or turning aside from troughs of softer rocks with an indifference to local structure which furnishes many striking examples of superimposition. In the basins of the softer Tertiary sediments or in the deeper and less resistant Excelsior beds the stages of the uplift are best shown. In these rocks the time of the first two stages was sufficient to allow the erosion of wide valleys with gentle slopes, which now stand in marked contrast to the more recent final gorge; but where the

[27] Bowman deduces an uplift at this stage of at least a mile, from evidence gained from study of stream profiles in southern Peru. Op. cit., p. 190.

stream started from the beginning of its rejuvenation to sink its channel in the harder rocks it was generally unable to widen its valley, even in the longer earlier episodes, and the entire erosion period is represented by a single sharp canyon.

The western streams were probably of consequent character, even on the old surface. The rejuvenation changed them to lively torrents; but, even with their steeper gradients, their headward erosion has been unable to compete with the greater eastern streams fed by the heavier precipitation on the Atlantic side. There is no evidence that they ever cut through the western wall into the plateau region. Generally, the lively erosion of the small but numerous Pacific streams has destroyed the earlier phases of the topography and reduced the valleys to steep-walled gorges—a condition which greatly hampers railroad development, but which has given Peru some of the most spectacular canyons in the world. Only in a few places, where the development of a drainage area has been checked by piracy of a more favorably situated river or where the advance of the modern gorge has been temporarily checked by a zone of resistant rocks, are the western streams still in valleys of the first or second stages of the uplift.

The Rio Santa, in the Department of Ancachs, is the only important western stream which is not of simple consequent character. In its upper course, through the famous Callejon de Huaylas, along the western side of the lofty Huascaran range, the river has developed its valley parallel to the northwest trend of the regional structure, from which it finally escapes to cut its way to the Pacific, through a gorge 10,000 feet deep, across the even ridge of the Cordillera Negra. The piracy by which the headward erosion of the Rio Santa captured the drainage of the shorter western streams was probably accomplished during the development of the Puna topographic stage, and the channel then established was maintained and strengthened throughout the period of later uplifts. With the diversion of the heavy run-off of the great snowfields of the Cordillera Blanca, a belt of high but dry country was left on the coast side, exposed only to the feeble attack of the direct western streams, crippled by their limited supply of water. The erosion accomplished by them, although by no means small, is insignificant when seen in contrast with the tremendous valleys and canyons carved out by the dominant stream which taps their original sources. The Cordillera Negra, which lies between the Callejon de Huaylas and the ocean, owes its existence to this piracy, which allowed a long strip of the old topography to be saved from the rapid erosion of the usual transverse streams.

In the latitude of Cerro de Pasco a belt of high country extends from the western range across to the eastern ridges and separates the drainage of the Marañon and Huallaga rivers (both tributaries of the Amazon) on the northern side from the drainage of the Mantaro to the south. This belt of high land is commonly called the Nudo de Pasco, and in all writings on Peru the impression is definitely given that it is a connecting range of mountains, structurally as well as geographically transverse to the trend of the Cordillera. This, however, is not the case. The Nudo de Pasco is merely a remnant of the old high surface (a little higher, due to the hills, of monadnock type, around Cerro de Pasco itself), which has been left as a bridge between the headward erosion of mighty and competing river systems of the eastern drainage. The Mantaro on the south and the Marañon and Huallaga on the north are the dominant streams of the plateau country in this section of Peru, and have so controlled its drainage and the drainage of both ranges that no direct eastern or western river has yet been able to work its way into the area. The Mantaro is weakest and the rate of its headward erosion at present is retarded by the basin of Lake Junin. The northerly flowing streams and two or more smaller but active streams direct from the east are in a race to capture the upper portion of the Mantaro drainage. Modern mining methods are aiding the attack of the Huallaga River by a drainage tunnel at Cerro de Pasco which diverts the underground waters into its basin, while the surface waters still follow a gentler slope to the Mantaro.

QUATERNARY AND MODERN GLACIATION

A lengthy period of glaciation, during which the higher valleys and ridges were scoured by active glaciers or buried under extensive icefields, and the valleys, even to low altitudes, choked by their outwash material, was the final episode in the history of the modern topography.

Undoubtedly the glaciation of the region was marked by several cycles of advance and retreat of the ice-front. In the valleys three distinct stages of glaciation, or at least three important pauses in the retreat of the ice from its greatest extent, may be clearly recognized, but indirect evidence of a still earlier period of glacial activity may be gained from the river terraces.

The earliest terraces indicate the filling of the valleys on the eastern side of the Continental Divide with coarse and poorly assorted gravels to depths of over 400 feet. Those deposits most likely resulted from overloading of the streams with glacial outwash material during the retreat of the first ice-sheet. Since that time the streams, in spite of one

or more similar interruptions, have succeeded in removing the greater part of the gravels and have cut their channels 150 to 200 feet deeper into the bedrock. All direct traces of the corresponding glaciation have naturally been obliterated, particularly by later and possibly more extensive advances of the ice. In the steeper western streams the gravels of this early period have been more completely removed and no remnants of them have as yet been recognized. One of the best examples of the gravels in the eastern streams is shown on the cliffs above the smelter at Oroya, where a section of the old channel of the Mantaro River is clearly exposed.

At the time of its greatest advance the ice in many valleys reached an altitude of 12,500 feet. A few glaciers, favored by extensive icefields and high gradients, extended as low as 11,000 feet. (The moraine below the gorge of Yanganuco, in the Huascaran range, is one of the lowest I have seen.) On the other hand, isolated highlands, even above 13,500 feet in elevation, are in places unglaciated, where no higher gathering ground for ice existed. Ice-caps, however, probably developed on every area higher than 14,000 feet.

The moraines of this early (though not the earliest) glaciation have generally been partly destroyed by erosion or buried by later gravels and are sometimes difficult to recognize. Striations, except on the hardest rocks, have likewise been obscured. The cross-profiles of the valleys, however, still show the U-shaped character, and hanging valleys are common. Postglacial stream-cutting is slight, except in unconsolidated gravels. Channels sunk in the bedrock are rarely over 60 feet in depth, except in soft shales. The amount of cutting is not comparable to the extensive erosion which followed the deposition of the first deep gravels, and it seems reasonable, therefore, to consider these first-mentioned deposits to be products of a much earlier glacial advance and retreat, of which the direct traces of ice-action have been practically obliterated.

Of the U-shaped valleys produced by the earlier glaciation, the chief modification has been caused by lateral filling, due to the development of talus cones and fans. These deposits have a tendency, especially when the valley is in relatively soft or fractured rocks, to convert the original U-shaped cross-profile into a modified V, which, in its complete development, is difficult to distinguish from a normal V-shaped stream valley. In most Andean valleys, however, the process has rarely gone far enough to obliterate the break in slope of the upper parts of the original U, but it has gone far enough to afford a distinct contrast to the higher valleys. produced by more recent glaciation, in which the talus action is negligible.

The second stage in the retreat of the ice, or possibly the maximum advance of a third cycle of glaciation, is marked by a series of large and almost unmodified terminal moraines which lie across the valleys at elevations between 13,500 and 14,200 feet. Above them the valleys are cleanly scoured U-shaped gorges, with polished and striated walls, with numerous small lakes in rock basins, and all the usual features of intensive recent glaciation. Postglacial erosion is practically lacking, except where narrow channels have been cut through unconsolidated moraines. Modification of the cross-profiles by talus has hardly started. The time which has elapsed since the retreat of the glaciers of this state is many times less than the time which separated it from the preceding period of more extensive glaciation.

From the moraines of this stage the retreat of the ice was too rapid to leave more than a few feeble deposits. No notable pause can be detected until the large and recent moraines close to the present glaciers are reached. These deposits occur at altitudes ranging from 15,000 to 16,000 feet, and many of them are now only 50 to 200 feet below the ends of the existing glaciers. They are hardly worthy to be classed as markers of a definite stage in the history of glaciation, yet their recent formation gives them importance. Twenty years ago the ice was close behind them. Since then it has retreated several hundred feet and the present ice ends against small lakes or has retreated back over bare rock.

Almost all peaks which rise over 16,500 feet support glaciers, and those over 17,500 feet usually give rise to extensive icefields, which support many long valley glaciers, the greatest of which extend as low as 15,000 feet.

The crest of the Cordillera in this section of Peru is not continuously ice-clad, but along the western range sections greater than 20 miles without snow peaks are rare, and the icefields about several clusters of lofty peaks are comparable to the greatest in the Alps or in the Canadian Rockies. The Cordillera Blanca, which culminates in Huascaran, 21,700 feet in altitude, somewhat north of the area discussed in this paper, probably supports the most extensive glaciers in Peru, but they are rivaled and possibly surpassed by the icefields of a group of little-known peaks 60 miles or so northwest of Cerro de Pasco, whose highest mountain (the Nevada de Huayhuas) attains an altitude of 20,850 feet. Impressive glaciers cluster about many of the lofty but isolated peaks of the eastern range, but unbroken icefields for any important distance are rare. The ridge to the east of the Huancayo Valley supports the most extensive glaciers on the eastern Andes in this section of Peru. The

entire district offers fascinating fields for exploration and glacial research. Comparisons of the extent of present and past glaciation on the western and eastern ranges would be of great interest and might yield some definite information concerning the climatic history of the region.

OXIDATION AND SECONDARY ENRICHMENT OF SULPHIDE DEPOSITS

Exceedingly favorable physiographic conditions for the thorough oxidation of superficial portions of sulphide deposits undoubtedly existed during the formation of the early surface of low relief (Puna stage). Where ore bodies still outcrop on this surface, or on the gentle slopes of the Junin stage, a complete and fairly deep oxidized zone generally exists, and beneath it, where chemical and mineralogical conditions were favorable, a well-marked zone of secondary sulphides. Oxidation and enrichment usually have not been able to keep ahead of the more rapid erosion of the later cycles, and fresh sulphides or only partially oxidized sulphides are exposed at the surface where the deposits are within reach of the rapid erosion in the modern canyons. Only where remnants of the old surface exist are oxidized or secondary ores to be expected.

Glaciation in the high ranges has usually scoured off most of the oxidized cappings that may have developed during the early erosion cycle, but in the plateau country the ice was more sluggish and was able only to polish the silicified and limonitized outcrops. It rarely cut deeply enough to expose the underlying sulphides. Postglaciation oxidation and enrichment are negligible.

Conclusion

To point out the problems which still need to be settled rather than to summarize results already accomplished is probably the most important service that can be rendered in a new field. The broad features of the geology of the region may properly be considered fairly well established, but on several critical points our knowledge is still very incomplete.

The classification and sequence of formations, developed independently in the course of our work, largely concerned with structural and lithologic features, is in complete agreement with the order based on paleontologic work by the Peruvian geologists. The division of the conformable Mesozoic limestones, however (that is, the recognition of the Triassic beds at the base of the Pucará or Paria limestone, the subdivision of the Machay limestone, and the recognition of the Jumasha limestone), de-

pends chiefly on evidence of paleontologic nature, whereas the grouping of the later formations is based almost entirely on structural and lithologic evidence.

The ages of the metamorphosed sediments of the Excelsior series and the sands and gravels of the Mitu formation are still indefinite, but an exact determination will be difficult on account of the lack of fossils. An acceptable correlation might possibly be made with known Silurian and Carboniferous beds, respectively, based on other points of similarity.

A study of the variation and distribution of type of material in the Goyllarisquisga-Jatunhuasi formation and in the later terrestrial and shallow-water sediments might lead to reliable conclusions regarding the form and position of the landmasses from which they were derived.

The most interesting and the most important problem still in an unsatisfactory state is the determination of the age of the Shuco limestone conglomerate, the Pocobamba formation, the Cassapalca red beds and related formations. Evidence from more localities is needed to confirm the conclusions concerning the structural relations stated on pages 610-614, but the greatest need is for paleontologic evidence of definite nature. Search for fossils so far has been fruitless, but it is reasonable to believe that they may yet be found. Without their evidence the Tertiary age of these formations can hardly be accepted as established. The proper understanding of all later phases in the geologic history of this portion of the Andes depends on the determination of the age of the red beds, and consequently its importance can hardly be overemphasized.

The later volcanics, which overlie the red beds, present an abundance of evidence concerning the nature and mechanics of formation of pyroclastic rocks and their relation to explosive vents. They are receiving detailed study at present in the course of our geologic work in the Casapalca district.

A host of unsettled points arises in connection with the stocks of intrusive rock which flank the axis of the western range. The details of their relations to the regional structure are of particular importance, but more numerous observations will be required before definite conclusions can be stated. The nature of their differentiation, the relation between type of rock and area exposed, and the association between type of rock and mineralization are among the problems which demand further investigation on a regional scale.

Very considerable information has already been gathered, particularly in the detailed study of mineral districts in this section of Peru, but fascinating ground still remains to be covered. The field, considered as

a metallogenetic province, offers material for abundant research. Its many ore deposits are sufficiently varied and distinct to relieve the region of any charge of monotony, but yet possess enough features in common to indicate suggestive relationships which offer hope of leading to generalizations of practical as well as scientific importance.

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CORRELATION OF RESIDUAL EROSION SURFACES IN THE EASTERN APPALACHIAN HIGHLANDS[1]

BY ELEANORA BLISS KNOPF

(*Read before the Society December 27, 1923*)

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Introduction

The numerous interruptions in the erosional history of the Atlantic Slope recognized in recent years has emphasized the importance of a correct correlation of the remnants of the erosion surfaces that were produced during the successive interrupted cycles.

Several years ago the writer made some detailed studies of the topography in the region between the New Jersey Highlands and Catoctin Mountain, in Maryland, on the one side and the western border of the Coastal Plain on the other side. These studies showed that there exists in the highlands of the region a series of level terrace-like surfaces, and that these surfaces bevel the upturned underlying rocks. Moreover, in the lowlands flat-topped hill summits of accordant elevation, which also bevel the underlying structure, are obviously remnants of old surfaces of low relief into which the present streams have incised their meandering course. The large number of residual erosion surfaces thus suggested could not be fitted into the earlier ideas that the topography of this region has been developed in three erosion cycles; nor could they be explained by a widespread warping of two or three uplifted peneplanes,[2] such as had been invoked by Campbell in order to explain the occurrence of his uplifted Harrisburg peneplane at varying elevations in different places. The succession of numerous flat surfaces, one above the other, cutting across the underlying rock structure of the highlands, and the appearance of the same levels on both sides of the highlands areas made the warping hypothesis inadequate to reduce the number of erosion cycles indicated by the successive levels to the three cycles previously recognized; but the difficulty in correlating these many different remnants of erosion, preserved on the hill summits of the lowland and in the terrace levels of the highlands, was so great that the work was finally laid aside for lack of conclusive evidence for correlation.

Ideas of earlier Investigators

The idea of numerous erosion cycles in the evolution of present topography is not a new one, for as early as 1894 Keith[3] had pointed out that remnants of five peneplanes exist in the Appalachians of Maryland and Virginia. At about the same time he[4] showed that the present topography of the Southern Appalachians has been formed by the work of

[2] In this paper the writer has followed the usage of D. W. Johnson, who uses "peneplane" to signify an erosion surface of moderate relief produced near the end of an erosion cycle, restricting the term "plain" to a low relief region of horizontal rocks.

[3] Arthur Keith: U. S. Geol. Survey, 14th Ann. Rept., pt. II, 1894, pp. 366-395.

[4] Arthur Keith: Bull. Geol. Soc. Am., vol. 7, 1896, pp. 519-525.

numerous interrupted cycles rather than in a few of prolonged duration; but up to 1912 the majority of workers on eastern Atlantic physiography were still trying to explain the numerous remnants of erosion surfaces by the conception of three prolonged erosion cycles, and the topographic forms produced during these cycles were considered to be the work of subaerial denudation.

In 1912 Barrell[5] presented the revolutionary concept that the southern New England peneplanes are of marine origin. In the marine terraces thus recognized he was able to show the results of numerous cycles of erosion.

Still later Barrell[6] and Bascom[7] conclusively showed that the region between the Appalachian Valley ridges and the Coastal Plain furnishes evidence of numerous interrupted erosion cycles of relatively short duration, and level interfluves at various elevations were recognized as remnants of old peneplanes cut during these different cycles; but the proper correlation and the sequence of these remnants of peneplanes or partial peneplanes was still a tantalizing problem, since the elevation of residual erosion surfaces depends so largely on the relative resistance of different rocks and on the distance of each part of the surface from baselevel.

The work of Barrell was a distinct step forward toward evolving something definite out of the earlier generalizations on the topographic history of the region, and the writer was encouraged to resume work in the hope that some reliable evidence could be found for correlating the remnants of so-called peneplanes. An added stimulus was given to the present investigation by discussion of its problems with Dr. H. H. Robinson, of Yale University, to whose kindness the writer is especially indebted for helpful advice and criticism in the preparation of the manuscript.

The superimposed character of the master streams of the Atlantic Slope, combined with the extensive stream adjustment of the tributaries, suggested the possibility of tracing backward, step by step, the drainage history of the region, thereby determining the sequence of past cycles whose record is preserved in present and preexistent drainage channels and establishing the connection between such records of old drainage and the so-called peneplane remnants preserved in the level surfaces of the region.

[5] Joseph Barrell: Abstracts in Bull. Geol. Soc. Am., vol. 24, 1913, pp. 688-696.
[6] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, pp. 228-428.
[7] F. Bascom: Jour. of Geol., vol. 29, 1921, pp. 540-559.

Evidence of former drainage Courses

General statement

In a region where the streams have become thoroughly adjusted the present drainage system will retain little evidence of its former course. However, in spite of extensive stream adjustment, successive rejuvenations may be recorded in the drainage of a region in one or more of four ways: (1) Superimposition, (2) modification of normal cross-profiles of stream valleys, (3) wind gaps, (4) knickpoints,[8] or points of abrupt change in the longitudinal profile of stream valleys.

Superimposition

The unadjusted course of superimposed major streams across ridges that have been carved out by tributary streams indicates a reduction of the region to a low-lying plane surface before the formation of the flat-topped ridges. If the original plane surface was of marine origin and covered by sediments, the drainage that has cut through the sedimentary cover is said to be superimposed by sedimentation on the underlying hard rock. If the plane surface on which the consequent drainage has established its unadjusted course was formed by subaerial erosion, the drainage is superimposed by planation. Whether the plane surface that antedated the ridges was of marine or subaerial origin does not affect the value of the evidence of planation that is afforded by the superimposition. Streams once firmly intrenched in a superimposed course cut down across the hard ridges in valleys that will persist as long as the hard rock stands up above the level of the surrounding country. So a superimposed stream will record the peneplane on which it originally flowed as long as the flat top of the ridge remains unreduced, which may be through many subsequent partial cycles of erosion. But while a stream gap proves a superimposition that dates back to the time of formation of the highest flat-topped surface on either side of the gap, the shape of the cross-section of the gap is the only clue to the erosion history of the region subsequent to the intrenchment of the old stream.

Cross-profiles of stream valleys

The cross-profiles of rejuvenated stream valleys will show the outlines of wide older valleys into which the present streams are trenched. Composite valley slopes that indicate by their shape one or two rejuvenations

[8] Knickpoint, derived from the German "knikpunkt," is used by chemists to denote an abrupt change in direction from a gentle concave curve to a curve that is convex upward.

in the course of normal erosion have been aptly termed by Matthes[9] "two-story valleys" or "three-story valleys." But, although the evidence of the oldest rejuvenations may be preserved in the composite upper slopes of the valley, the presence of a uniformly steep inner gorge does not indicate that the gorge has been formed during an uninterrupted erosion cycle. On the contrary, the down-cutting of the lower gorge may continue during several partial cycles of erosion; for, even though the progress of erosion in the region be quickened by an uplift or by successive uplifts, there can be no record of such quickenings in a gorge through hard rock, if lateral planation has not yet begun to take effect. In the vicinity of the hard ridge softer rocks may have been reduced to a local peneplane, not once but repeatedly, while the gorge was simply being deepened.

WIND GAPS

The volume of water and the debris carried in the main stream of a superimposed drainage is much greater than in the tributaries; therefore down-cutting progressed most quickly in the master valley, and the minor streams have been, one by one, diverted from their superimposed courses by the subsequent tributaries of the master stream. The relic valleys of the original transverse minor streams are preserved as wind gaps in the hard ridges. Keith[10] and Barrell[11] have emphasized the value of wind gaps as indicators of fluvial baselevels. Briefly stated, the value of wind gaps in fixing points on partially obliterated drainage systems lies in the fact that their present outline has been comparatively little modified since the time when water was flowing through them, because they are hung up, so to speak, out of reach of subsequent erosion.

The stage of erosion at which capture took place may be inferred from the form of the cross-section of the wind gap, and from the elevation of the base of the wind gap compared with the elevations of contemporaneous stream channels recorded elsewhere in the region in the upper slopes of composite valleys. The subaerial erosion cycle during which any one series of wind gaps was cut can be fixed only by the correlation of the wind gaps with composite slopes in the adjoining stream valleys and with remnants of erosion surfaces whose present altitude shows an evident relation to the base of the wind gaps.

The value of the three evidences of past drainage that has been discussed above lies in the fact that in resistant rocks all three kinds will be preserved as long as the ridges stand above the surrounding lowland.

[9] Francois Matthes: U. S. Geol. Survey, Yosemite Valley, map, 1922.
[10] Arthur Keith: U. S. Geol. Survey, 14th Ann. Rept., pt. 2, 1894, p. 389.
[11] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, p. 338.

They will thus persist long after all other indications of the original drainage course have been destroyed by extensive stream adjustment and by repeated planations of the surrounding country. In addition, there remains, in the existent drainage courses of a region, still a fourth evidence of recent breaks in the continuity of erosion, namely, the knickpoints in the longitudinal stream profiles.

LONGITUDINAL PROFILES OF STREAMS

Since erosion progresses headward when a region is uplifted by a uniform tilting movement, except under the rare condition where the rate of erosion is equal to the rate of uplift, the longitudinal profiles of those streams will record a knickpoint at the headward limit of quickened erosion. Above this point the stream will be flowing on the gradient developed in the preceding cycle. Therefore a stream that has become intrenched in a peneplane and has maintained its course through several partial erosion cycles can show, from mouth to source, evidence of successively older periods of uplift and consequent valley cutting.

Relative Preservation of successive Drainage Courses

In a region that has been repeatedly uplifted we find near the seacoast widespread and clear records of the work of recent erosion. The dissection of successively emerged continental shelves by extended streams and the rejuvenation in the stream profiles in both recent and older stream courses, combined with the presence of residual deposits, make it comparatively easy to fix the duration and extent of each successive advance and withdrawal of the sea; but planation near sealevel, whether subaerial or marine, has been at a maximum in every cycle; therefore near the present shoreline the clearness of the record of recent erosion is combined with an obliteration of the record of earlier erosion cycles. The record of earlier erosion must be sought farther inland, near the present headwaters of streams, where isolated residuals of earlier plane surfaces have been preserved from dissection and where hard ridges that have not preserved their original surfaces during the peneplanation of adjacent soft rocks retain, in a more or less ephemeral way, the records of earlier erosion in the form of wind and water gaps.

Therefore, in order to trace the effects of successive rejuvenations, it is necessary to study the course of a major drainage system from the mouth to a point so far remote from present baselevel that the record of the old drainage channels is still preserved in the cross-profiles of the valleys.

Method of present Investigation

The present study covers a region lying between the Delaware and the Susquehanna rivers and extending from sealevel to the crest of Blue Mountain ridge (figure 1). It comprises: (1) Study of interstream areas that are remnants of former peneplanes or of incompletely developed peneplanes; (2) study of progressive stream adjustment and of the modifications of stream gradients and valley profiles during successive cycles of erosion. The work was carried on by a detailed map study, by the

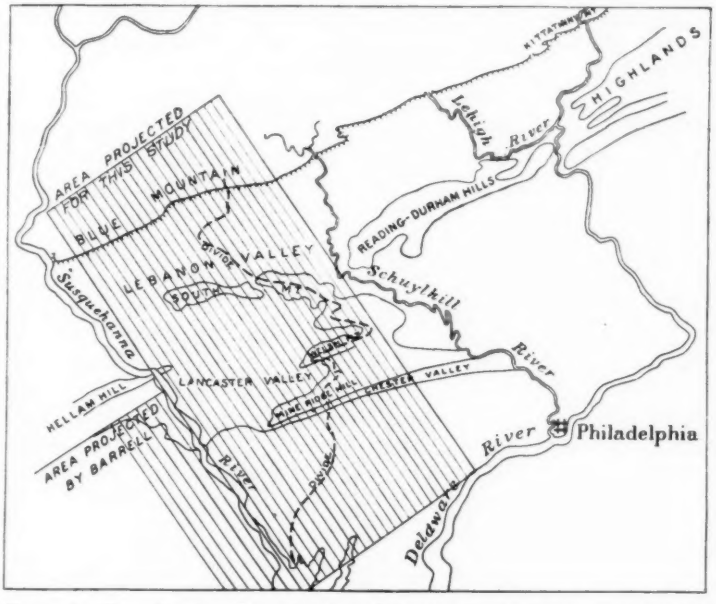

FIGURE 1.—*Map of eastern Pennsylvania and Portions of New Jersey and Maryland Southeast of the Appalachian Valley*

construction of projected profiles that extended the work of Barrell on the Piedmont terraces of Maryland, by the construction of numerous divide and stream profiles, and by the building up of a series of paleophysiographic maps that show an approximate restoration of the topography of the region at the close of each successive cycle or partial cycle of erosion. Extensive field-work in a large part of the region studied has enabled the writer to check a number of the conclusions reached in this work, but more detailed physiographic field-work over the whole area will be necessary in order to test thoroughly their value.

The physiographic principles involved in this study of drainage history are well known. In 1896 Campbell[12] made an attempt to apply them to the drainage history of the Southern Appalachians. More recently, in 1917, Barrell[13] called attention to the significance of valley forms in the recognition of recurrent uplifts. In the work on which he was engaged at the time of his death[14] he stressed the importance of present and past valley forms in the determination of fluvial baselevels; but up to the present time no systematic study has been made of drainage modifications in the region studied. The present work, however, is to be regarded more as a reconnaissance than as a detailed study of the problem, and is here presented as a suggestion of the desirable results that may be attained by such a method of attack on unraveling physiographic history and in the hope that the results may prove a stimulus to a more comprehensive study of stream modification and its bearing on the correlation of residual erosion surfaces in general.

Study of interstream Areas

The flat-topped interstream areas were first outlined on good topographic maps of a scale of 1:62,500. The individual levels thus established were then studied in their extended development across a wide stretch of country by the construction of projected profiles adjoining the northwest side of the area projected by Barrell, in Maryland, along a section plane running north 35½ degrees west from Baltimore. This area of Barrell's projection extended northeastward as far as the mouth of the Susquehanna River, at Havre de Grace, and northwestward as far as Parrs Ridge. The adjoining projection extended the foreground of Barrell's projection toward the northwest as far as the southeastern ridges of the Appalachian Valley (figure 1). The area thus projected embraces the plane surfaces that are upheld in the Blue Mountain-Kittatinny Ridge and the Lebanon Valley divisions of the Great Appalachian Valley, in the South Mountain and Reading-Durham ranges of the Appalachian Mountains, in the Lancaster Valley and the Triassic lowland divisions of the Piedmont Province, and in the Piedmont Upland to its junction with the Coastal Plain (figure 2).

The striking difference between this projection and that of Barrell, farther southeast, is that while Barrell's projection shows only a series of terraces, rising to successively higher levels, cut across rocks of approximately uniform resistance, this projection extends northwest of the

[12] M. R. Campbell: Jour. of Geol., vol. 4, 1896, pp. 568-678.
[13] Joseph Barrell: Bull. Geol. Soc. Am., vol. 28, 1917, pp. 761-765.
[14] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, pp. 333-348.

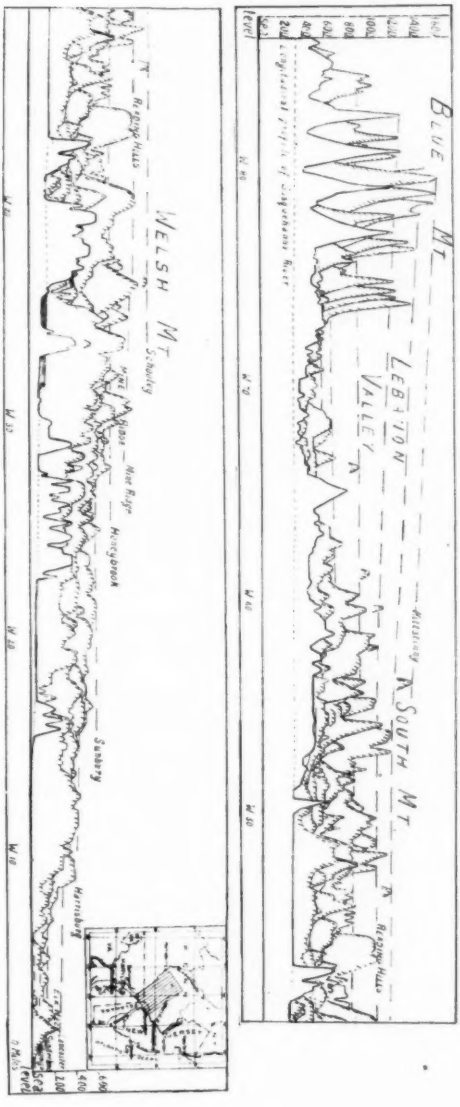

FIGURE 2.—*Projected Profiles of Area between Blue Mountain and Coastal Plain*

Parrs Ridge axis and shows the recurrence in the limestone lowlands northwest of Parrs Ridge of those levels lower than the crest of the ridge that are so well shown in Barrell's seaward-sloping terraces.

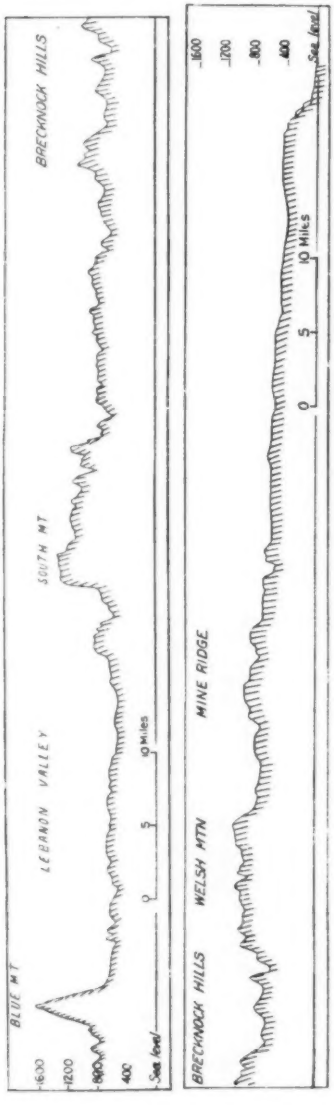

FIGURE 3.—*Profile of Divide between Susquehanna and Schuylkill drainage Systems*

The complexity of levels shown in such an extended projection is at first sight bewildering and is increased by the fact that in passing eastward from the Susquehanna Valley certain apparently level surfaces show a rise toward the watershed. For example, along Lebanon Valley the 400-foot level on limestone hills, near the Susquehanna, at 400 feet, rises to about 500 feet 6 miles northwest of Wernersville. The reason for the disappearance of the 400-foot surface near the watershed is that on existent divides remnants of surfaces cut during previous cycles are more or less immune from the destructive agencies of the present cycle. The profile of the divide between the Susquehanna and the Schuylkill drainage (figure 3) shows three conspicuous highlands occupied respectively by the Blue Mountains, South Mountain, and Welsh Mountain - Barren Hill ridges. The southernmost highland terminates in Mine Ridge at an elevation of about 900 feet. These highlands are separated by intervening lowlands that are about 20 miles in width. Although Blue Mountain lies 24 miles farther inland than South Mountain, the general elevation of the intervening lowland is

more than 100 feet lower than the general elevation of the lowland that separates South Mountain and Welsh Mountain.

The most striking feature of the divide is the difference between the portion that extends seaward from Mine Ridge and the inland extension northward from Mine Ridge. This ridge marks the northeastward continuation of the Parrs Ridge axis, and south of the upland the profile of the divide is strikingly similar to Barrell's projected profiles of the Piedmont terraces in Maryland. The descent from Mine Ridge to sealevel comprises a succession of seven stepped, or terrace-like, surfaces that are cut across crystalline schists of approximately uniform resistance to erosion. The outline of these steps is not regular in its linear extent as in a flight of stairs, but each successive level wraps around the dissected edges of the next higher level, thereby extending headward up the courses of the major tributaries.

In New England it was such a stairlike arrangement of levels, facing seaward, that suggested to Barrell the idea that the rises are old sea-cliffs. In the Pennsylvania terrace-like surfaces the marine origin of the treads is suggested by their gentle seaward slope, lack of monadnocks, and scarplike descent to the next lower-lying level. The three lowermost terraces, each carrying a well-defined mantle of unconsolidated deposits, are of Pleistocene age and are generally conceded to be of marine origin.

In the absence of marine deposits and of conclusive sea-cliffs, the origin of the four upper terraces must still remain hypothetical, but whatever was the erosional process that produced the level, terrace-like surfaces, the uniformity of resistance in the underlying rock leads one to conclude that they are distinct surfaces of denudation, partially dissected, the width of each step being dependent on the duration of the erosion that produced the plane surface.

The dissected character of the divide north of Mine Ridge presents a strong contrast to the terrace-like steps south of the ridge and is indicative of subaerial erosion. The divide is notched by depressions that fall into two classes. The first class, to which belong only a few of the numerous depressions, comprises narrow, steep-sided transverse trenches sunk into flat-topped uplands. Their shape clearly shows that they were carved by the erosion of former streams. The second class, which is represented by the majority of depressions, embraces the wide, gently rounded, col-like depressions that suggest at first sight a normal lowering of a divide crest by headward erosion of opposing streams. But these notches are not depressions in a sharp crest, such as would be expected if the lowering were due to streams contesting a narrow divide. On the contrary, they extend with level floors for a half mile or more in a direc-

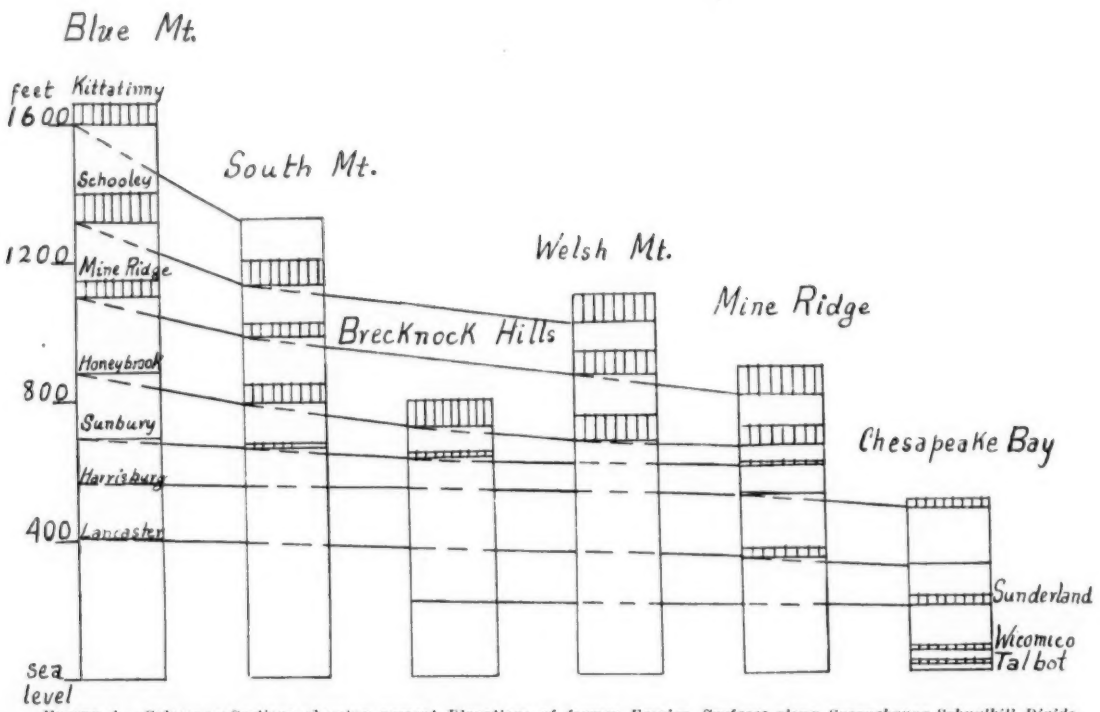

FIGURE 4.—*Columnar Sections showing present Elevations of former Erosion Surfaces along Susquehanna-Schuylkill Divide*

level

FIGURE 4.—*Columnar Sections showing present Elevations of former Erosion Surfaces*

TABLE I

BARRELL		BASCOM				ELEANORA B. KNOPF					
NORTHERN APPALACHIAN HIGHLANDS		PIEDMONT PROVINCE OF PENNSYLVANIA				REMNANTS OF EROSION SURFACES ESTABLISHED BY PRESENT INVESTIGATION					
	Fluvial baselevels	Peneplains	West	East			Pocono Mountain	Blue Mountain and vicinity	South Mountain	Welsh Mountain and vicinity	Mine Ridge southward to sealevel
Kittatinny	1,600 feet	Kittatinny	1,800	1,600	1,100	Kittatinny	1,800	1,660	1,340		
Schooley (?)	1,350 feet	Schooley	1,300	1,000	900	Schooley		1,400–1,300	1,180–1,100	1,080	
						Mine Ridge		1,100–1,000	1,000	940	900
?	950 feet	Honeybrook	860	800	700	Honeybrook		900– 840	840-800	800–720	720
Sunbury	750 feet	Harrisburg	800		500	Sunbury		700– 600		620	620
Harrisburg	520 feet	Early Brandywine[15]	500	400	390	Harrisburg (Bryn Mawr?)		560– 500			500–460
		Terraces									
Somerville	400 feet	Late Brandywine	400	300	200	Lancaster (Brandywine?)		440– 400		420	320
		Sunderland	300	180	100	Sunderland					200–100
		Wicomico	90		45	Wicomico					80– 60
		Talbot	45	40	0	Talbot					40

[15] This name is now replaced by Bryn Mawr. F. Bascom: Resuscitation of the term Bryn Mawr gravel. U. S. Geol. Survey Prof. Paper in preparation.

tion at right angles to the trend of the divide; and this suggests their origin as wind gaps which have been abandoned by their streams in a late mature stage of erosion. If these depressions along the divide are really the result of stream erosion in previous erosion cycles, the elevation of the base of the depressions should coincide with remnants of erosion surfaces in other parts of the region, such as benches, shelves, or hill summits.

By careful study of different localities it is possible to determine for each the relative position of the various erosion surfaces, and this may be conveniently recorded in the form of a columnar section. The columnar sections made along the line of the Susquehanna-Schuylkill divide profile are shown in figure 4. The first column shows the present elevations of former surfaces of erosion along the Blue Mountain ridge. The range in elevation of the same surface at various points along the ridge is indicated by the ruled blocks. The second and fourth columns show the former erosion surfaces in South Mountain and Welsh Mountain respectively, and the third column shows the disappearance, in the intervening Brecknock Hills lowland, of the two highest erosion surfaces that are preserved in South and Welsh Mountains. The fifth and sixth columns are built up from the elevations of the terraced levels that slope seaward south of Mine Ridge. The gradient of each surface as represented in the figure is only relative, as the horizontal distance on the figure is not drawn to scale.

As these columnar sections show, there were successive fluvial erosion cycles whose resultant surfaces now stand at elevations ranging from 40 feet above sealevel near Havre de Grace to 1,660 feet on the summit of Third Mountain, in the Appalachian Valley ridge.

In Table I the baselevel and erosion surfaces recognized by Barrell and Bascom are tabulated for comparison with those determined by the writer in the region studied.

Comparison shows that the results of the present study bear out to a large extent the conclusions of Barrell and Bascom and also suggest the existence of an additional erosion cycle, here called the Mine Ridge cycle because the surface developed during the cycle is well preserved on the flat summits of Mine Ridge.

Study of drainage Modifications

GENERAL STATEMENT

The lines of evidence on which the above conclusions are based are derived from the study of drainage modifications. They are presented in some detail for each successive cycle or partial cycle of erosion.

[a] This name is now replaced by Bryn Mawr. F. Bascom: Resuscitation of the term Bryn Mawr gravel. U. S. Geol. Survey Prof. Paper

KITTATINNY CYCLE OF EROSION

At the close of the earliest erosion cycle that is recorded in the region, the surface from Blue Mountain to the present seacoast had been reduced to a peneplane, as shown by the flat tops of accordant altitude that form the crest of the Blue Mountain-Kittatinny range, by the superimposition of the main streams and of tributaries across the ridge, the evidence of the tributaries being recorded in numerous wind gaps. The dissected remnants of this surface, known as the Kittatinny peneplane, are well preserved at about 1,660 feet elevation in the level summits of Kittatinny Mountain on either side of Delaware Water Gap. No evidence was discovered during the present work to indicate whether the peneplane was marine or subaerial in origin.

SCHOOLEY CYCLE OF EROSION

The next cycle of erosion reduced a long section of Blue Mountain to a low-lying plane surface, now standing at elevations between 1,300 and 1,400 feet. This 1,300–1,400-foot level is developed near the master stream valleys, on one or both sides of the water gaps, and extends for a distance that varies in relation to the importance of the stream that flows through the gorge. Thus the summit on the east side of the Delaware Water Gap is the Kittatinny level, but on the west side of the gorge the Kittatinny level is reduced for a distance of 5 miles. Similarly, the reduction of the Kittatinny surface covers a distance of about 5 miles east of Lehigh Gap, about 6 miles on either side of Schuylkill Gap, and about 25 miles on either side of the Blue Mountain Gap of the Susquehanna where Kittatinny residual summits are found only in the summits of Third Mountain, about 4 miles northwest of the Blue Mountain front. This obliteration of the Kittatinny surface over such a wide extent, on both sides of the present gaps through which the Susquehanna crosses the Appalachian Valley ridges, indicates the dominance of the Susquehanna over the Delaware drainage system. This dominance, which originated in such a remote erosion cycle as the Kittatinny, has persisted until the present day, when the area of the Susquehanna River drainage basin (27,000 square miles) exceeds that of the Delaware by 15,000 square miles.

Evidence of the erosion cycle that dissected the Kittatinny surface on Blue Mountain is also found in the numerous shallow depressions between 1,440 and 1,300 feet that trench the 1,660-foot summit levels, and in the gentle upper slopes of the composite valley profiles of the deep gaps incised in the Kittatinny level. South of Blue Mountain the region

was reduced to a peneplane whose remnants are now preserved at about 1,160 feet in the summits of Schooley Mountain and South Mountain and about 1,180 feet in Welsh Mountain. Proof of this Schooley peneplanation is found in the superimposition of the streams, as shown by the wind gaps and composite valleys that trench the level Schooley summits of the New Jersey Highlands (Table II).

TABLE II

Probable Wind Gaps recording Schooley Erosion that dissected the Kittatinny Peneplane

Locality	Name	Elevation of base, in feet	Elevation of adjoining summits, in feet
Blue Mountain....	1. Longs Gap.....	1,390	1,580
	2. Cranes Gap.....	1,320	1,480
	3. Thirteen miles southwest of Port Clinton.	1,440	1,660
	4. Three miles northeast of Port Clinton.....	1,420	1,600
	5. Ten miles west of Lehigh Gap.....	1,280	1,600
	6. Lehigh Furnace Gap...	1,305	1,600
	7. Fox Gap.....	1,380	1,600

Present Elevation of Valleys cut during Schooley Erosion, as shown in the restored Cross-profiles of Composite Valleys

Lehigh Gap.....	1,300	.....
Pen Argyl.....	1,380	.....
Delaware Gap.....	1,380	.....
Little Gap.....	1,300	.....

At South Mountain a flat-topped summit, preserved on resistant quartzite, at an elevation of 1,320 feet, rises 200 feet above the level of the Schooley surface. The relation between the Kittatinny surface and the younger erosion surface on Blue Mountain corresponds so well to the relation between the highest summits of South Mountain and the widespread lower surfaces that it seems probable that the 1,660-foot surface in Blue Mountain is identical with 1,320-foot summits in South Mountain, and that the post-Kittatinny surface at 1,300 to 1,400 feet in Blue Mountain is identical with the Schooley peneplane as preserved in the level summits of the New Jersey Highlands at 1,160 feet. Confirmatory evidence of this correlation is found in the longitudinal profile of the Susquehanna River, which is discussed in a later section.

MINE RIDGE CYCLE OF EROSION

The recognition of the succeeding Mine Ridge cycle rests on the existence of a well-defined level surface on South Mountain below the remnants of the Schooley peneplane. This lower surface suggests a dissection of the Schooley surface, with the resultant formation of the present 1,000-foot level. A study of the Blue Mountain profile shows the record of this erosion cycle in a series of wind gaps whose bases lie between 1,100 and 1,200 feet, at a lower elevation than the gaps recording the Schooley channels (Table III).

TABLE III

Probable Wind Gaps recording Mine Ridge Erosion during which the Schooley Peneplane was dissected

Locality	Name	Elevation of base, in feet	Elevation of adjoining hill summits, in feet
Blue Mountain.....	Myers Gap.....	1,180	1,340
	Millers Gap.....	1,180	1,340
	Little Gap.....	1,100	1,440–1,500
South Mountain.....	Transverse depressions along divide crests...	1,000–1,080	1,200

Present Elevation of Valleys cut during Mine Ridge Erosion, as shown in the restored Cross-profiles of Composite Valleys

Blue Mountain.....	Manada Gap.....	1,200	1,340
	Indiantown Gap.....	1,200	1,300
	Swatara Gap.....	1,180	1,440

These lower gaps indent the Schooley surface, preserved between 1,300 and 1,400 feet, and trench the mature Schooley valleys. This post-Schooley valley cutting therefore coincides with the development of a peneplane or partial peneplane south of Blue Mountain whose remnants are at lower elevations than the residuals on Schooley Mountain. Such a wind gap recording Mine Ridge erosion is Little Gap, 5 miles northeast of Lehigh Water Gap (figure 5). Little Wind Gap, whose base lies at 1,100 feet, records three erosion cycles. The oldest is represented by the Kittatinny surface, the record of succeeding Schooley stream-work is retained in the upper slopes of its composite valley profile, and the lower steep gorge records the quickened erosion of the Mine Ridge cycle.

Therefore, during the erosion cycle that succeeded the Schooley, Blue Mountain was dissected to a depth now recorded at 1,100 feet. Local plane surfaces were also cut in the vicinity of South Mountain that are recorded in plateau remnants at about 1,000 feet, and the region south of South Mountain was reduced to a partial peneplane whose remnants

are so well preserved at about 800 feet in Mine Ridge that this erosion cycle is called the Mine Ridge cycle. That the flat-topped summit of Mine Ridge was originally part of a widespread surface of low relief is proved by the transverse course of the stream that once flowed across the ridge at Gap, where the old valley is preserved as a wind gap.

The duration and extent of erosion during the Kittatinny cycle is problematical, because so few remnants of the Kittatinny peneplane remain that the full extent of the surface can not be estimated. It must have been considerable, for the Kittatinny peneplane extended southeastward from Blue Mountain for a distance of at least 30 miles, as

FIGURE 5.—*Photograph of Little Wind Gap, 5 Miles Northeast of Lehigh Water Gap, looking North*

Foreground shows Sunbury erosion surface at 700 feet; skyline shows the Kittatinny peneplane along the summit, a valley of the Mine Ridge cycle at 1,100 feet in the base of the composite wind gap, and a valley of the Schooley cycle in the lateral slope on the east side of the gap. Photograph by Joseph Barrell.

shown by remnants of the old Kittatinny erosion surfaces preserved in the isolated summits that rise to 1,300 feet in the New Jersey Highlands and the Reading-Durham Hills. The succeeding cycle of erosion must have been long enough to remove practically all of the Kittatinny surface south of Blue Mountain; yet the total uplift on Blue Mountain was not more than 300 feet. Such an uplift would hardly furnish stream activity sufficient to completely degrade the region south of Blue Mountain—a fact which suggests that the Schooley peneplane south of Blue Mountain

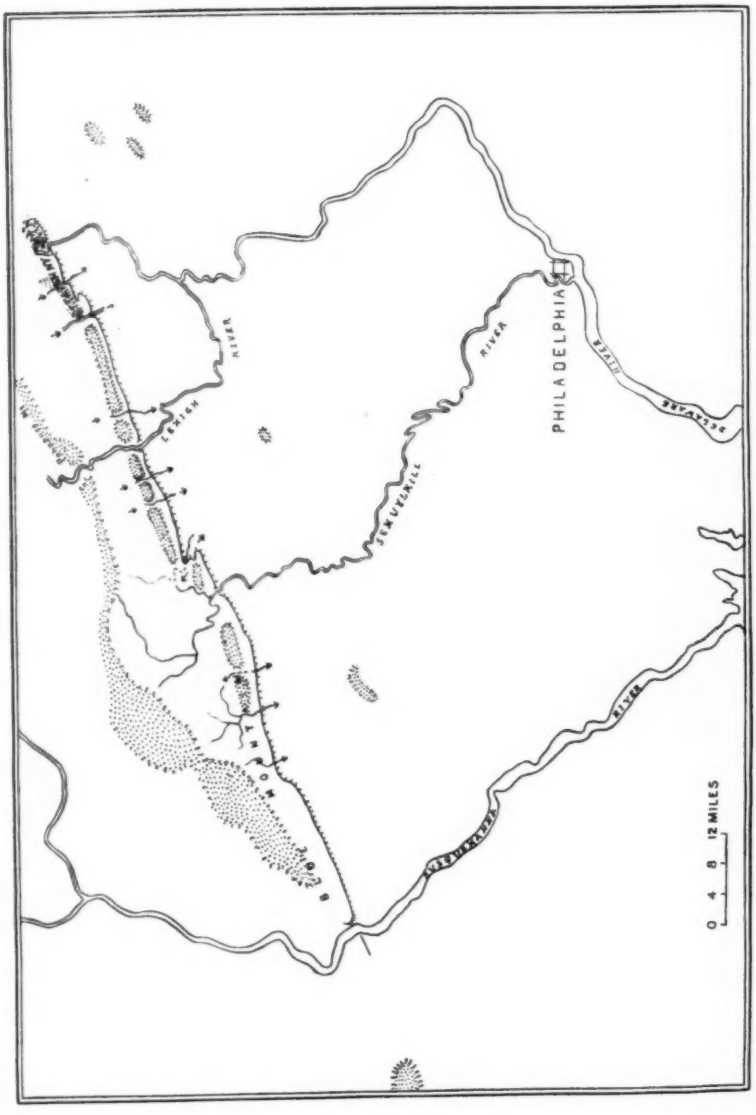

FIGURE 8.—*Generalized Topography of the Region at the Close of the Schooley Cycle*

FIGURE 6.—*Generalized Topography of the Region at the Close of the Schooley Cycle*

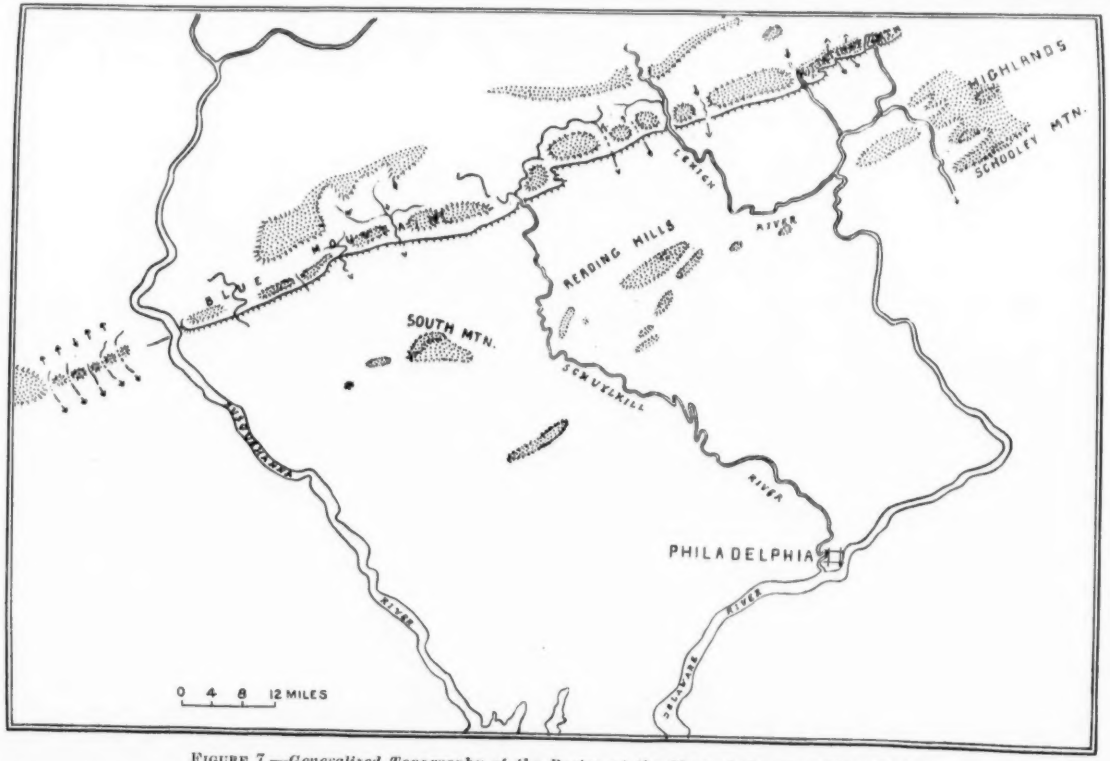

FIGURE 7.—*Generalized Topography of the Region at the Close of the Mine Ridge Cycle*

Peneplaned surfaces are shown in white. Unreduced highlands are dotted. The maps show the present course of the master streams. Arrows indicate the former course of minor drainage lines. Broken lines in a stream course indicate wind gaps.

was formed by marine denudation rather than by fluvial erosion. During the Mine Ridge cycle planation was less extensive and the highlands of the present topography began to appear, but, with the exception of a few notches in South Mountain that are possibly wind gaps, there is no evidence to prove the subaerial origin of this partial peneplane south of Blue Mountain or to indicate the extent to which it was developed eastward.

The paleophysiographic maps shown in figures 6 and 7 are approximate restorations of the topography of the region at the close of Schooley and Mine Ridge erosion cycles. It is probable that more residuals of Kittatinny erosion persisted through the Schooley cycle than are shown on the map, for Kittatinny residuals that did not yield to Schooley erosion may have been favorably located to attack during the Mine Ridge cycle and thus may have succumbed during the later cycle.

HONEYBROOK SUBCYCLE OF EROSION

The rejuvenation that interrupted the continuity of erosion during the Mine Ridge cycle was recognized by Bascom[16] in the remnants of surfaces now preserved at 720 feet, near Honeybrook, Pennsylvania. As a result of this rejuvenation, terraces were cut on the resistant slopes of Mine Ridge at 720 feet. South of Mine Ridge the seaward planation of the Honeybrook cycle is preserved in the terrace-like surface at 720 feet. In Blue Mountain, streams quickened by the Honeybrook uplift cut deep gorges that were abandoned by their streams in consequence of the next rejuvenation to erosion. They stand now as the well-known wind gaps at Pen Argyl Gap (980 feet), Culver's Gap (920 feet), and Sterrett Gap (920 feet). The present study suggests that the slate foothills of Kittatinny Mountain, rising to 840 feet southwest of Delaware Water Gap, record a local plane cut during Honeybrook erosion, and that the Pen Argyl wind gap is the result of stream capture during an early stage of the erosion that cut the plane at 840 feet. Stream action during the Honeybrook cycle is also shown in terraces at 940 feet on the cross-profiles of the Susquehanna and Manada gaps through Blue Mountain and is suggested in the wide depression at 960 feet into which Heckert Gap is trenched. Barrell[17] recognized such an erosion cycle, whose baselevel is now preserved at 940 feet in the vicinity of Kittatinny Mountain and at 950 feet north of Dingmans Ferry, in a shelf along the Delaware River.

[16] F. Bascom: U. S. Geol. Survey, Folio No. 211, 1920, p. 2.
[17] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, p. 341.

SUNBURY SUBCYCLE OF EROSION

The work of the next succeeding cycle has been fully outlined by Barrell[18] for the region between Sunbury and Harrisburg. He named the resultant surface the Sunbury peneplane because remnants are well preserved at about 850 feet in the flat hilltops near Sunbury, Pennsylvania. Below the level of the Kittatinny Mountain foothills, at 840 feet (Honeybrook peneplane), Sunbury planation is also to be recognized in the general level of 700 feet in the hilltops of the slate belt near Bangor (figure 8). These level hill summits grade northward into a well-defined system of cusps or terraces at 720 feet that encircle the Kittatinny foothills at 840 feet north of Bangor. The attainment of a local peneplane in this region during Sunbury time is proved by the superimposed course of the Delaware River north of Easton, where a gorge 600 feet deep has been cut through the resistant ridge, whose summit reaches over 700 feet in Marble Mountain and Chestnut Hill.

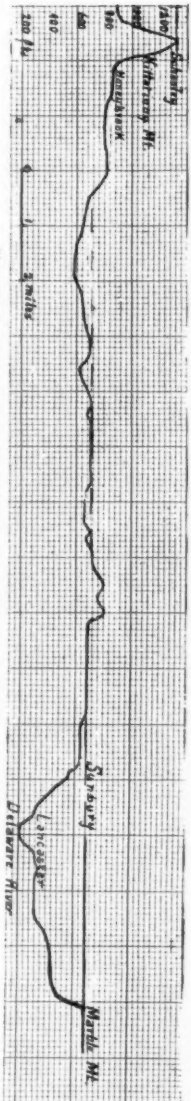

FIGURE 8.—*Profile of Divide between Delaware River and Martins Creek*

It is possible that at this stage of stream development the river that was cutting the Marble Mountain gorge continued directly northward through the valley at present occupied by Martins Creek (figures 9 and 10), and that during Sunbury and pre-Sunbury time there were two parallel southward-flowing streams, one occupying the Martins Creek-Marble Mountain Valley and the other occupying the present channel of the Delaware south of the water gap as far as Belvidere.[19] At Belvidere, instead of making the present sharp turn to the southwest, the second stream pursued a southward course through the present Pequest Valley. The present southwestward course of the Delaware between Belvidere and the mouth of

[18] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, p. 336.

[19] The reader is advised to refer to the following topographic sheets of the U. S. Geological Survey: Delaware Water Gap, New Jersey-Pennsylvania; Easton, New Jersey-Pennsylvania; Hackettstown, New Jersey; High Bridge, New Jersey.

Martins Creek is parallel to the strike of limestone and was probably during Sunbury time a tributary to the extended Martins Creek that flowed south through Marble Mountain. The lithologic control of the underlying limestone enabled the tributary to deepen its valley more rapidly than the Delaware-Pequest River could erode the resistant crystalline rocks of the Highlands, and the tributary eventually captured the

FIGURE 9.—*Sketch Map showing, a, present Course of Martins Creek and of Delaware River between Belvidere and Easton, Pennsylvania*

Delaware at Belvidere, leaving the evidence of the former southward course of the Delaware at this point in Van Nest Wind Gap (620 feet) and the wind gap north of Port Colden (620 feet), through which the Delaware may have once found its way into the Raritan Valley.

The elevation of the base of these two wind gaps shows that they continued to be a watercourse throughout the erosion cycle that succeeded the Sunbury, whereas the stream that flowed through Stewart Gap (740

feet) and through the gap at 740 feet north of Port Murray was diverted from its course in the early stage of the post-Sunbury cycle. Barrell has called attention to the existence of wind gaps that appear to mark Sunbury erosion at 750 feet in Rattlesnake Ridge 20 miles northwest of the Susquehanna water gap through Blue Mountain. In Mine Ridge a Sunbury stream channel is preserved in the wind gap at Gap, whose base lies at 580 feet.

FIGURE 10.—*Sketch Map showing, b, possible Course of Martins Creek during the Sunbury Subcycle of Erosion*

The paleophysiographic maps of the region near the close of Honeybrook and Sunbury erosion (figures 11 and 12) show that the outlines of the present highland areas south of Lebanan Valley were clearly delimited and persistent, thus indicating that the normal progress of erosion was interrupted before either cycle had attained even approximate completion. The shoreline probably lay southeast of Mine Ridge, for old

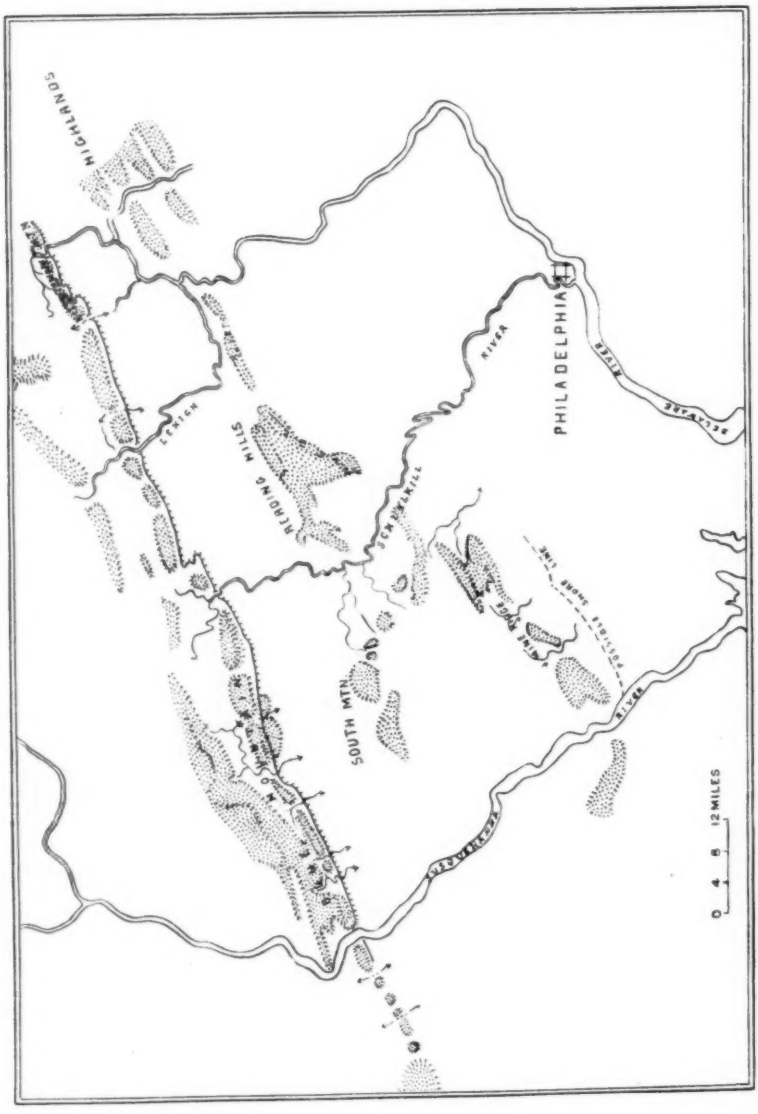

FIGURE 11.—*Generalized Topography of the Region at the Close of the Honeybrook Subcycle*

FIGURE 11.—*Generalized Topography of the Region at the Close of the Honeybrook Subcycle*

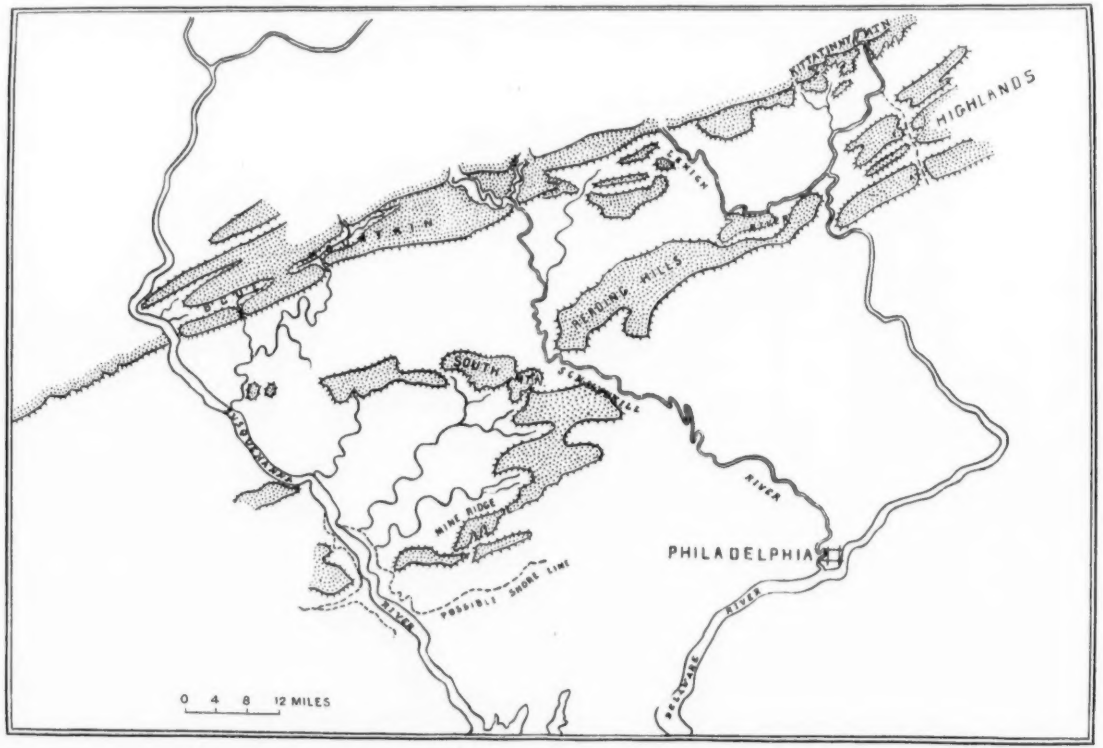

FIGURE 12.—*Generalized Topography of the Region at the Close of the Sunbury Subcycle*

Peneplaned surfaces are shown in white. Unreduced highlands are dotted. The maps show the present course of important streams. Arrows indicate the course of former drainage lines. Broken lines in a stream course indicate wind gaps.

drainage courses recorded in the highlands north of Mine Ridge point to a persistence of fluvial erosion in that part of the region throughout Honeybrook and Sunbury time. Gravel has been found by the writer at 620 feet on North Valley Hills, about 3 miles northwest of Coatesville, and by Barrell[20] on the 730–745-foot terrace near Reisterstown, Maryland. It is significant that Barrell considered the latter gravel to be of marine rather than fluviatile origin. So far as the writer knows, this gravel has not been found on these levels except in that part of the region where the extent and character of the 740- and 620-foot surfaces is suggestive of marine terracing.

HARRISBURG (BRYN MAWR?) SUBCYCLE OF EROSION

The upland surface underlain by Martinsburg shale north and east of Harrisburg shows vestiges of two erosion surfaces. A local peneplanation is recorded in the general upland surface at about 520 feet and remnants of an earlier planation rise above the 520-foot level in isolated monadnocks with an elevation of 660 feet. These upper residuals approximate the present elevation of the Sunbury peneplane in the Harrisburg quadrangle. It is suggested, therefore, that the name Harrisburg used by Campbell, who was the first to point out the operation, in this region, of more than two erosion cycles,[21] be restricted to the surface now preserved at 520 feet in the vicinity of Harrisburg. Barrell[22] ascribed to the remnants of Harrisburg erosion north of Harrisburg a gradient of 2 feet per mile, and this slope projected southward would place Harrisburg residual surfaces near Chesapeake Bay at an elevation of 440 feet. This level accords with the 460-foot surface at Woodlawn northeast of Perryville. North of Woodlawn and south of Chester Valley the same surface is well developed at 500 to 460 feet. At Woodlawn this plane surface bevels the underlying Cretaceous deposits and gravel formerly mapped as "Lafayette."[23] It was later pointed out by Bascom and Miller[24] and others that the gravel originally called "Lafayette" and later known as Brandywine[25] formation really occupies two levels, separated by a considerable age break. The higher-level gravel, which is the equivalent of the deposits at Woodlawn, is now called by Bascom[26]

[20] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, p. 426.
[21] M. R. Campbell: Bull. Geol. Soc. Am., vol. 14, 1903, p. 284.
[22] Joseph Barrell: Am. Jour. Sci., vol. 49, 1920, p. 336.
[23] G. B. Shattuck: Maryland Geological Survey, Rept. on Cecil County, 1902, p. 166.
[24] F. Bascom and B. L. Miller: U. S. Geol. Survey, Folio No. 211, 1920, pp. 2, 12.
[25] W. B. Clark: Am. Jour. Sci., 4th series, vol. 40, 1915, p. 499.
[26] F. Bascom: Resuscitation of the term Bryn Mawr gravel. U. S. Geol. Survey Prof. Paper in preparation.

Bryn Mawr gravel, because that name was used by Lewis[27] for deposits on the "Upland Terrace," which included both the 400- and 300-foot levels. The deposits at Brandywine, Maryland, occupy the lower of the two levels. If the gravels on the 420-foot surface at Bryn Mawr and on the 460-foot surface at Woodlawn should prove to be marine deposits on a wave-cut plane that is the equivalent in age of the subaerial erosion surface now lying at 520 feet near Harrisburg, Harrisburg erosion would be contemporaneous with early Brandywine or Bryn Mawr deposition. However, until the equivalence of deposition and erosion can be definitely established, it is the opinion of the writer that a separate name should be used to denote the erosion surface and the gravel. The name of the gravel in parentheses after the name of the erosion surface suggests the tentative correlation.

LANCASTER (BRANDYWINE?) SUBCYCLE OF EROSION

History.—South of Harrisburg the surface of the shale hills descends abruptly from the 560-foot level to a wide lowland at about 400 feet underlain by calcareous rocks. This lowland, although known as the Lebanon Valley, is not genetically related to one stream, for Swatara Creek, which occupies the valley for a portion of its course, flows out of the limestone into the shale hills, utterly regardless of lithologic control. South of Lebanon Valley, Lancaster Valley stretches out in a wide, gently undulating surface of low relief, underlain by limestone and dolomite. About 130 square miles of country east of the Susquehanna River maintains an approximate level of 380 to 420 feet. Above this level rise the low ridges whose summits are remnants of the dissected Harrisburg peneplane. That the 400-foot level is due to erosion and not to the character of the underlying calcareous rock is established by the fact that the surface bevels the folded schist, limestone, and dolomite in the area of the McCalls Ferry quadrangle east of Pequea Creek and north of the Martic Hills. South of Conestoga the presence of a notch 100 feet deep, whose base is at an elevation of 400 feet, suggests a probable wind gap, which therefore fixes a point on a stream that dissected the Harrisburg peneplane.

The remarkable incised meanders of Swatara and Conodoguinet Creek were evidently initiated on the level surface of the local peneplane formed by Harrisburg erosion and cut down during the erosion that dissected the Harrisburg level. The lowlands of the present topography are therefore due to post-Harrisburg planation, whereas the surface that is repre-

[27] H. C. Lewis: Proc. Acad. Sci. of Phila., vol. 32, 1880, pp. 269-277.

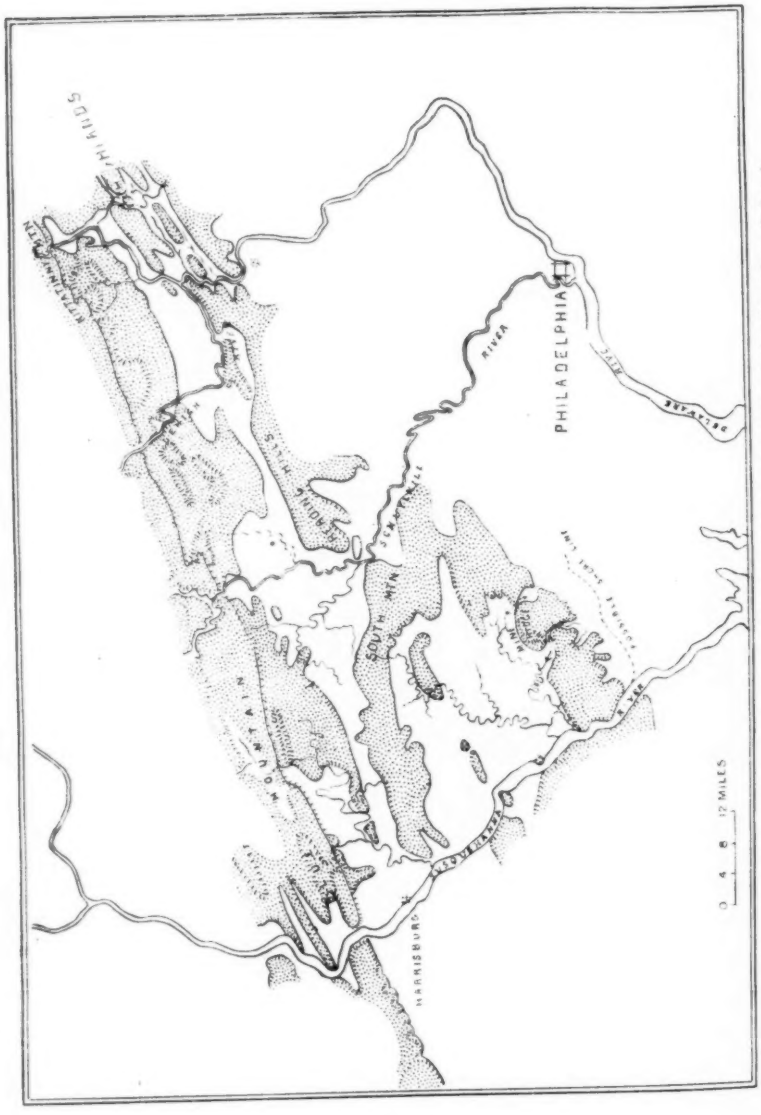

FIGURE 13.—*Generalized Topography of the Region at the Close of the Harrisburg Subcycle*

FIGURE 13.—*Generalized Topography of the Region at the Close of the Harrisburg Subcycle*

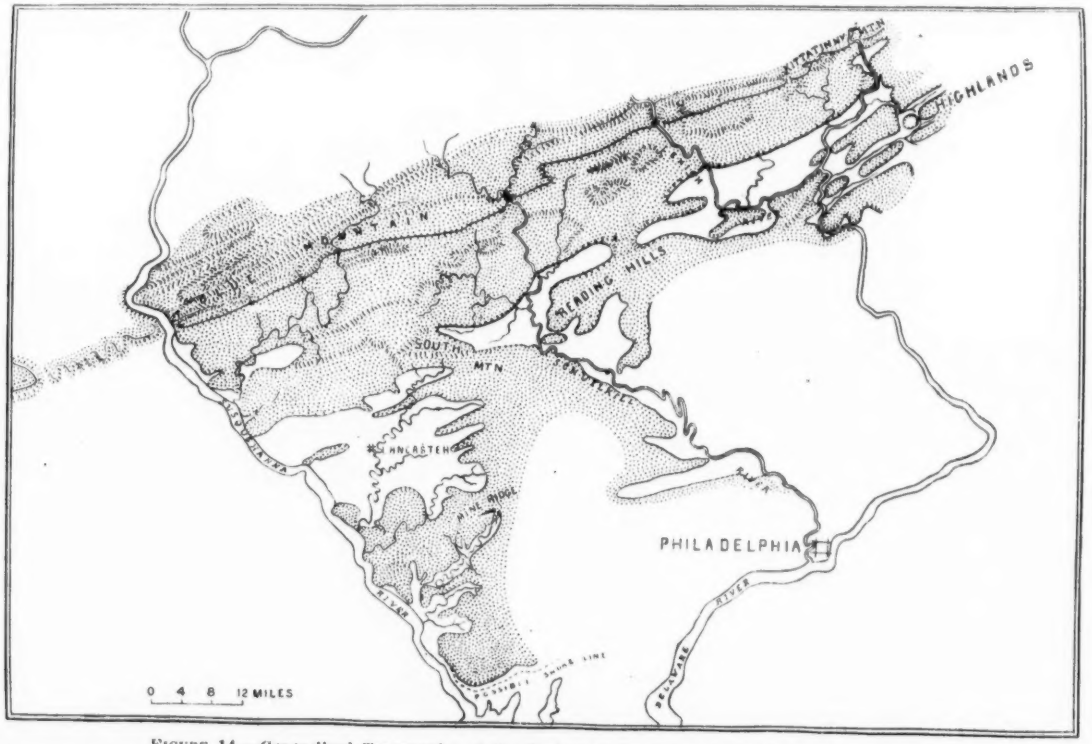

FIGURE 14.—*Generalized Topography of the Region at the Close of the Lancaster Subcycle*

Peneplaned surfaces are shown in white. Unreduced highlands are dotted. The maps show the present course of the most important streams. Arrows indicate the course of former drainage lines. Broken lines in a stream course indicate wind gaps.

sented by the rolling hills that bound the wide lowlands have been formed during the Harrisburg erosion.

The duration of the erosion that dissected the Harrisburg surface was relatively short, as pointed out by Campbell,[28] who called attention to the rise of the country underlain by limestone to over 500 feet on the divide between the Susquehanna-Schuylkill drainage. Similarly, on the divide between the Schuylkill and the Lehigh the 400-foot level is absent, showing that the Lancaster planation, although relatively extensive where the underlying rock is soft, was confined to areas near the master streams and nowhere succeeded in reducing the divide, which is also on soft rock, to the level of Lancaster Valley.

The brief time during which the limestone was being planed down is also shown by the fact that south of Mine Ridge the widespread surface at 380 to 400 feet is lacking, but is replaced by a well-defined terrace at elevations of 320 to 340 feet. This terrace can be followed up the valleys of the Susquehanna and its tributaries for a certain distance and then disappears, being replaced farther upstream by another terrace at a higher level. The point on the stream valley where the 340-foot terrace disappears is marked by a break in the longitudinal stream profiles, thus indicating the headward limit of rejuvenated erosion for the partial cycle that cut the stream terraces at 320 feet. Although this partial cycle lasted only long enough to permit stream terracing of valleys cut into resistant rocks in southern Pennsylvania, a local peneplane was developed, farther north, across the easily eroded limestones of the Lancaster Valley (figures 13 and 14).

Name.—The 380- to 420-foot surface in the region east of the Susquehanna appears to correspond to what has been called the Somerville plain by Campbell.[29] But the name Somerville has been used to describe a low-lying surface that occupies much of the Piedmont area in New Jersey and slopes southeastward within the Raritan quadrangle from an altitude of 200 to 300 feet near the base of the Highlands escarpment to about 100 feet in the southeast corner of the quadrangle.[30] This gives a slope of 11 feet per mile, which is excessive and undoubtedly indicates the presence of more than one plane of erosion. In the neighborhood of Frankfort the local plane surface at 140 feet, carrying Pensauken gravel, is probably equivalent to the surface having the same elevation around Somerville.

[28] M. R. Campbell: Bull. Geol. Soc. Am., vol. 14, 1913, p. 283.
[29] M. R. Campbell: Bull. Geol. Soc. Am., vol. 14, 1903, p. 283.
[30] W. B. Bayley, H. B. Kummel, and R. B. Salisbury: U. S. Geol. Survey Raritan Folio No. 191, 1914, p. 3.

The name Somerville, as originally used, clearly embraces several different erosion surfaces, and because the surface around Somerville was developed later than the local peneplane preserved in the floor of Lancaster Valley, the latter can not now be considered Somerville. The name "Lancaster subcycle" will therefore be applied to the erosion stage that resulted in this local peneplane in Lancaster Valley. It is possible that the Lancaster fluvial erosion surfaces can be correlated with the marine gravel of the Brandywine that lies at an elevation of 230 feet at the type locality in Maryland. This gravel is undoubtedly the equivalent of the low-level Brandywine gravel at elevations of 200 feet in Elk Neck, on the eastern shore of Chesapeake Bay. The relation of the late Brandywine[31] surface to the Sunderland terrace on Elk Neck corresponds so closely to the relation between the 320-foot Lancaster terraces along the Susquehanna and the Sunderland terraces at 200 to 220 feet that the equivalence of Lancaster and late Brandywine erosion is suggested.

LATE PLEISTOCENE EROSION

The quickening effects of late Pleistocene uplifts are recorded in both the cross-profiles and the longitudinal profiles of the Susquehanna Valley and its tributary valleys, in the extended streams that cross the emergent terraces, and in the recently initiated streams whose headwaters have never cut back of these terraces. The intervening submergences are recorded in the extension of the terrace deposits up the valleys cut in the next older terrace.

Before the recent drowning, which formed the large estuaries of the Atlantic coast, an uplift had brought above sealevel a plain carrying deposits of Talbot age. Above the scarp that separates this Talbot plain from the next higher level the quickened upland streams were cutting back their courses with renewed activity, while they extended their courses seaward in new valleys, dissecting the Talbot surface. The amount of erosion accomplished before the subcycle was interrupted by submergence was slight, for in the longitudinal stream profile of the Susquehanna the lowest knickpoint marking the headward limit of rejuvenation is a break in the normal concave slope at 40 feet above sealevel.

Corresponding knicks in the profiles of the minor streams that drain from the uplands across the emerged terraces into Chesapeake Bay indicate that the inland extent of the erosion rejuvenated by post-Talbot uplift was very short in the minor streams and only about 10 miles along the master stream.

[31] F. Bascom: U. S. Geol. Survey Folio No. 211, 1920, p. 3.

Post-Wicomico emergence carried rejuvenation along the Susquehanna about 24 miles from the mouth to an elevation of 120 feet, where the sudden change in gradient has caused a waterfall now utilized as a source of power by a large hydroelectric plant. The third significant knickpoint along the Susquehanna, at 250 feet, 58 miles from the mouth, marks the headward limit of post-Sunderland stream-quickening.

The next knickpoint on the Susquehanna profile occurs at 340 feet, near the mouth of Juniata River. The erosion whose headward extent is marked by this point corresponds to the plane surface, at approximately 400 feet, in the Lebanon-Lancaster lowlands, and thus establishes the position in the erosion sequence of the lowest erosion surface recognizable in the sections between Blue Mountain and South Mountain. The determination of this lowest erosional plane, as formed by pre-Sunderland erosion, confirms the correlation of the 1,160-foot Schooley surface in South Mountain with the post-Kittatinny erosion that formed terraces and plateaus at 1,400 to 1,350 feet in Blue Mountain (see page 646).

SIGNIFICANCE OF KNICKPOINTS IN STREAM GRADIENTS

The climate changes during the Pleistocene influenced the eroding power of streams over the region as a whole and would not, therefore, produce knickpoints on the stream gradients. In estimating the significance of discontinuities in the curve of a river gradient, the character of the river bottom must be considered. A steepening of the curve at a point where the river channel passes from limestone into quartzite, or *vice versa*, would obviously have no bearing on the upstream limit of accelerated stream-cutting. The three points of sudden steepening in gradient, which are here connected with the three Pleistocene uplifts, can not be explained by any change in rock bottom of the river. It is an interesting fact that these three points are marked by waterfalls of sufficient importance to furnish sites for two existent and one projected hydroelectric plant. Waterfalls are often caused by a local uplift across the course of a stream, which will cause a knickpoint in the stream gradient, as in the case of Muscle Shoals, on the Tennessee River.[32] But the value of knickpoints in recognizing regional uplift lies in the fact that the headward limit of stream rejuvenation caused by such an uplift will be recognizable, not only in the main stream, but also in the tributaries, at points which clearly are not conditioned by local factors, such as bedrock, faulting, or local upwarping.

[32] M. R. Campbell: Jour. of Geol., vol. 4, 1896, p. 667.

Paleophysiographic Records shown in Course of Octoraro Creek

The profile of Octoraro Creek, a long tributary to the Susquehanna, epitomizes the physiographic history of the region during seven successive cycles or subcycles. The stream enters the Susquehanna 10 miles above the head of Chesapeake Bay, at an elevation of about 40 feet. This point marks the headward limit of post-Talbot erosion. The Octoraro pursues a meandering course across the Harrisburg erosional surface. Knicks in the longitudinal profile at altitudes of 120 and 220 feet mark the upper limits respectively of post-Wicomico and post-Sunderland rejuvenation, and from 220 to 440 feet on East Branch the profile shows an uninterrupted gradient that was assumed during Lancaster erosion. A cross-section of Octoraro Valley (figure 15) shows the

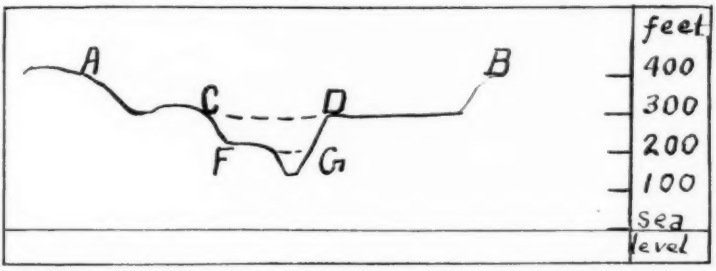

Figure 15.—*Cross-section of Octoraro Creek between Porters Bridge and the Mouth of Stone Run*

three-story valley formed by the intrenchment of the superimposed valley into the Harrisburg surface. A, B, C, D show the outline of the post-mature valley cut by the Lancaster erosion cycle, during which a rock bench at 300 feet was developed by lateral planation. Within this Lancaster Valley a shallow valley at C, D, F, G is associated with a similar bench at 220 feet. These 220-foot rock benches can be traced down the Susquehanna River to the mouth, where they appear to merge into the level occupied by remnants of Sunderland deposition. A steep-sided gorge trenched into this Sunderland valley was carved by post-Wicomico uplift.

Above 440 feet on the longitudinal profile of East Branch of Octoraro Creek the gradient steepens near the quartzite ridge of North Valley Hills. The fact that the steepened gradient lies within the limestone floor of Chester Valley shows that it can not be ascribed to the interposition of a hard layer in the stream course. Therefore, from 440 feet to the source at 560 feet, the stream is cutting in the channel assumed

during the Harrisburg erosion cycle. Directly above the source of the East Branch the wind gap at Gap records the course during Sunbury time when the ancestral Octoraro, that flowed through the gap, had its source north of Mine Ridge.

Mine Ridge is a local divide, and above the level of the wind gap the record of present stream courses fails and the evidence of previous cycles lies in the superimposition of the ancestral Octoraro across the Mine Ridge surface and in the shape of the composite valley of the wind gap, which records in its gentle upper slope the intrenchment of the superimposed stream, accompanied by extensive lateral planation during the Honeybrook subcycle, and in its steep inner gorge the down-cutting of the Sunbury valley, from which the Octoraro was diverted in the early stages of Harrisburg rejuvenation.

Sequence and Correlation of Erosion Records

It is possible, therefore, by an analysis of present and past drainage to show that eight successive uncompleted erosion cycles are recorded in the region between Chesapeake Bay and Mine Ridge. North of Mine Ridge vestiges of two older cycles are preserved in remnants of former erosion surfaces occupying the summits of South Mountain. Between South Mountain and the Appalachian Valley ridges advanced local planation during comparatively recent erosion cycles has removed the older erosion surfaces from the calcareous rocks in the lowland. The correlation between the older erosion surfaces in the adjacent highlands depends on a study of the longitudinal profile of the main stream, the Susquehanna, that drains the whole region.

Amount and Duration of Erosion

The relative amount and duration of erosion comprised in each of the ten complete or partial cycles of erosion whose operation has been indicated is impossible to estimate, because we have no means of determining either the maximum area under erosion during the older cycles, or the agency by which the work of these cycles was accomplished, or the rate at which it acted. During the Kittatinny cycle the region between South Mountain and Blue Mountain was reduced to a plane surface of low relief that was cut across the most resistant formations, giving for the region lying between the Delaware and the Susquehanna rivers a minimum area of planation amounting to 2,000 square miles, which is undoubtedly only a fraction of the original extent. In the succeeding three cycles the corresponding eroded area amounts to at least 5,000

square miles, but the reduction was much less complete than in the previous smaller area. It is evident that a large part of the 5,000 square miles was undergoing fluvial denudation, which progresses more slowly than marine planation, and the failure to reduce the region completely during all post-Schooley erosion may be due to the fact that the Kittatinny and Schooley peneplanes were formed by marine denudation, which planes down alternating belts of hard and soft rock with variable rapidity but with equal completeness. If, on the other hand, the 2,000 square miles that were planed down by Kittatinny and Schooley erosion were degraded under subaerial conditions, the length of these two cycles must have been appreciably longer than that of any succeeding partial cycle.

Periodicity of Uplift

Whatever the duration of the earliest cycles, it must be emphasized that the present study of the evolution of drainage in the region between the Appalachian Valley ridges and the Coastal Plain clearly disproves the idea of numerous successive peneplanations of the area, and at the same time equally clearly establishes the recurrence of numerous slight uplifts that caused repeated interruptions to the continuity of baseleveling. The three youngest uplifts were oscillatory in character along the inland margin of the present Coastal Plain. Whether the older uplifts were accompanied by similar oscillations in level is not clear, but the net result of coastal movement has been an intermittent elevation that has raised the Blue Mountain-Kittatinny range at least 1,600 feet in a *per saltum* series of slight uplifts. Such a succession of slight uplifts operating over a long time suggests a periodic relief of a steadily accumulating vertical strain. It is an interesting speculation whether such periodic movements record the periodic establishment of isostatic equilibrium along the border of an area of deposition rather than the continuous maintenance of isostatic balance demanded by the extreme isostasists.

Age of Erosion Cycles

The effect of such repeated uplift is to postpone indefinitely the total degradation of a region by constant addition to the area undergoing reduction and by setting back the progress of the work, so to speak, after each interruption. It is, therefore, idle to speculate as to the age of the oldest surface in the region on the basis of the probable time required to reduce such a surface to sealevel.

The evidence on the age of erosion cycles that is based on the correlation of the present slope of the old fluvial gradient with the present slope

of buried peneplanes is, perhaps, more reliable, and according to this criterion the gentle seaward slope of the old fluvial gradients suggests that no erosion cycle recorded in this region is older than late Tertiary.

Conclusion

Topographic records of physiographic history are imperfect and ephemeral. "The hills are shadows, and they flow from form to form, and nothing stands;" but it is believed that, by applying the principles governing drainage evolution and the method of drainage analysis here indicated, it is possible to prove the existence of successive erosion cycles and to correlate the remnants of peneplanes or of old erosion surfaces in regions that have been repeatedly uplifted.

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GENESEE GLACIAL LAKES[1]

BY G. H. CHADWICK AND E. U. DUNBAR

(Presented before the Society December 27, 1923)

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INTRODUCTION

In preparing the chart of the Laurentian Great Lakes already printed,[2] attention was directed to the effect of the recurrent ice-advances. The attendant correlation of moraines across country, and with lake beaches or outlets, found special application in a study of the Genesee Valley then under way,[3] whose present status is indicated by the tentative chart herewith presented. By the increase of levels 50 per cent over last year's chart, the opening statement of that previous paper is verified. More important, this study bears directly on any effort to evaluate the length

[1] Manuscript mailed to the Secretary of the Geological Society March 3, 1924.
Manuscript received by the Secretary of the Society March 10, 1924.

[2] Bull. Geol. Soc. Amer., vol. 34, pp. 499-506, chart on p. 506.

[3] Thesis by Miss E. U. Dunbar: "The Glacial Lake history of the Genesee Valley," on file in University of Rochester library. Most of the previous literature on this area is by Prof. H. L. Fairchild, from 1895 to 1923; see bibliography in Bull. 746, U. S. Geol. Survey, especially numbers 95*c*, *d*, 96*c*, 99*a*, *b*, 00*f*, *g*, 08, and 13.

of glacial time. Much of its detail must be left, however, to a more extended paper, to be published elsewhere.

Ice-readvances and Water-levels

First readvance; Valley Heads moraine

The Valley Heads moraine, which Chadwick correlated with the Imlay of Michigan is today the water parting for the Susquehanna drainage in New York and imprisons enormous "valley-train" fillings between it and the ancient rock-divides; yet in crossing the Genesee Valley at Portage no such valley-train lies south of it. Had the valley-filling accompanied *pari passu* the ice-recession, it must have filled the Genesee Valley as it did the neighboring valleys to the east. Since it did not so fill them, it is necessary to believe that the ice melted back rapidly, holding glacial lakes before it in all these valleys alike; then during a long pause (at the moraine) it poured out its detritus into the valleys that could drain away from it (now part of the Susquehanna system), completely filling them, whereas the Genesee Valley failed to fill because its drainage was toward the ice and its outflow washed the detritus eastward into Susquehanna waters.

In all probability the ice-front fell back farther to the north before it assumed a stand at the present moraine, thus permitting the local lakes of the Canisteo, Cohocton, and Genesee valleys temporarily to coalesce. For this inferred lake a name is proposed commemorating unpublished studies on this region by the late Prof. N. S. Shaler.[4]

Second readvance; Alden moraine

The details of the local falling waters between the Valley Heads and Alden stages must be omitted here; the chart expresses what is now known.[5] The intervening Hamburg and Marilla moraines had no known effect. Lake Arkona is shown as the lowest water-level reached during this recession, but it is rather likely that Arkona was followed by a lost interval of lowered easterly escape, or "free drainage," whose channels were wholly obliterated by the Alden readvance. The difficulty of reconstructing such a stage has caused its omission from the already overcrowded chart.

[4] This name has been used before, for a water body that appears to be mythical, at least not likely to be confused with this one.

[5] Compare also Bull. Geol. Soc. Amer., vol. 34, p. 503.

THIRD READVANCE; NIAGARA FALLS MORAINE

Following the Alden are the Buffalo and then the Niagara Falls moraines. The Niagara Falls readvance terminated the original "free drainage" episode described by Fairchild as marking an ice minimum, being thus the first oscillation to be recognized in that area. It is found, however, that the "free drainage" channels of this stage were overpassed by the Irondequoit ice-lobe during deposition of the Niagara Falls moraine and must therefore have been subsequently re-cut across this moraine between Mendon and Victor during an ice-recession preceding Lake Dana. The Niagara Falls moraine is represented south of the Irondequoit Valley by the great kame area of the Hopper Hills, which nearly unites at Ionia with the corresponding (more southerly) kame mass of the Alden moraine. The Hopper Hills sharply block and terminate the higher channels of the Honeoye-Mendon series.

It is still very uncertain whether this readvance restored Lake Hall as well as Lake Vanuxem, and there are yet very puzzling and unexplained features in the complex of moraines and "free drainage" channels west of the Genesee River that may compel a more varied history.

The Niagara Falls moraine is followed by the Barre, then the Albion.

FOURTH READVANCE; ALBION MORAINE

Taylor's tracing of the Albion-Pinnacle moraine into the Irondequoit Valley and across the Fairport Channel of Lake Dawson[6] has accomplished at least two things: It has linked this moraine with Lake Dana, as forecast by the writer,[7] and it has proved an ice-recession preceding Lake Dana sufficient in distance and in time to permit the cutting of the Fairport Channel. The main phase of Lake Dawson thus precedes Dana, and we have to insert a complicated history between Lake Warren and Lake Dana, including doubtless a fleeting preliminary flow through the Dana outlet at Marcellus, besides the recutting of the Mendon-Victor Channel, already necessitated.

In the previous chart this readvance was not given full recognition, while that indicated as preceding the later Dawson was incorrectly emphasized on the basis of a minor moraine which lies so close south of the Iroquois Beach or "Ridge Road" between Rochester and Sodus that if it signifies any readvance at all the preceding minimum must have permitted escapes for Genesee waters lower than the Fairport outlet. A very brief recession would have temporarily admitted Lake Iroquois it-

[6] Private communication from Mr. Frank B. Taylor of unpublished studies, here gratefully acknowledged.

[7] Proc. Roch. Acad. Sci., vol. 5, fig. 2, p. 127.

self, with intervening "second Dawson" stages whose channels would lie buried under both the moraine and the Iroquois attritus. The chart omits this possible but rather improbable oscillation.

Just such a "second Dawson" unquestionably existed next preceding the incoming of Iroquois, then 70 feet lower than the final Ridge Road shore, which involves a total lowering of 110 feet from Dawson to Iroquois. The outlet channels are partly visible south of the "ridge road" between Sodus and Williamson, but have been largely buried under the rising waters of Iroquois.

From this point onward the critical areas are far northward and are not so well known to the writer. There would seem, however, reason to admit at least one other readvance.

FIFTH READVANCE (?): COBBLESTONE HILL MORAINE

Long-lived lakes with outlets in essentially insecure (temporary) situations, such as Portage and Dana, exist on the crest of an ice maximum. It may be that such was the case also with Lake Emmons (Frontenac). If so, then the preceding minimum must have let Lake Vermont for the moment into the Ontario Basin, which it later reoccupied for a longer time.

Taylor recognizes four moraines between the Albion and Cannon Corners.

SIXTH READVANCE (?)

During the final expansion of Lake Vermont into the Ontario Basin and the following early stage of Gilbert Gulf, the rate of land uplift was at a maximum in the Saint Lawrence Valley, permitting the Algonquin River at Trent, Canada, to cut far below the marine summit beaches and even below the present water-level of Lake Ontario before Lake Algonquin was turned to Port Huron outlet.[8] The long pause that followed, before resumption of rapid uplift in Nipissing times, seems to indicate one more (and final?) ice-readvance, whose corresponding moraine must lie somewhere north of Quebec, where there are a considerable number to choose from. This supposed sixth readvance was followed by initiation of Lake Ontario.

[8] It will be observed that a different explanation is here given to the phenomenon on which Professor Coleman based his "Admiralty Lake" (A. P. Coleman: "Glacial and Post-glacial Lakes in Ontario," in University of Toronto Studies, Biol. Ser. no. 21, pp. 31-32, 49-52, 71). This should not be construed as a denial of the existence of such a lake stage, but rather as an alternative hypothesis while awaiting fuller knowledge.

The Readvances and the astronomic Cycle

We come thus to the basic question of the meaning of these larger readvances, especially their time value. In the chart, six advances have been recognized. There is room for argument as to the right number; it may be greater, just possibly it was less. One to four lesser moraines each time lie between those found to affect lake levels. The evidences of readvance are convincing for the Alden, Niagara Falls, and Albion stages, reasonably sure for the Valley Heads, but inferential only for the Cobblestone Hill (Cannon Corners) and supposed later stage.

For experimental purposes, it was assumed in building the chart that these particular moraines mete out uniform portions of time; nevertheless time ratios within each such cycle have been but crudely shown, legibility of the chart being paramount and a determination of the actual succession of events being prerequisite to refinement of ratios. Eventually each individual water body must be restudied in the field to reach an estimate of its life span from its beaches, deltas, or outlet channel. No one who has seen these features can doubt that much time is needed, but the importance of such exact study now becomes apparent for the first time.

If we assign to these indicated oscillations the time period of the Croll cycle, approximately 26,000 years, and then compare with estimates derived from other data by other workers,[9] they are found to be of a length about double the accepted estimates. Thus the Niagara Gorge is allowed 60,000 years as against Spencer's 39,000 and Taylor's 20,000 to 35,000; the time since initiation of Lake Iroquois is 54,000, while Coleman has 25,000, the lifetime of that lake being 12,000 as against his 8,000. Lake Ontario is given 14,000 years, where Coleman obtained 8,000 from excellent data and Spencer insists on only 3,500.

It is hardly safe as yet to assume that these discrepancies rule out the Croll cycle. For one thing, they affect only the later part of the chart, in which the number of major readvances is least certain; and again, in a problem of so many unknown factors, any solution may be an underestimate. The rate of carving of Scarborough Cliffs, for instance, has been modified by fluctuations of Lake Ontario level. The conflicting figures are still at least of the same general order of magnitude.

[9] Mostly summarized by Coleman on pp. 65-72 of paper cited. See Folio 190, U. S. Geol. Survey; also Evolution of the Falls of Niagara, Geol. Survey Can., 1907, and Am Jour. Sci., vol. 63, n. s., p. 360.

Other Causes of Pulsation

We are led, nevertheless, to consider other possible causes of rhythmicity, more flexible, perhaps, than an astronomic cycle. The experiments of Tarr and von Engeln[10] offer a novel explanation, for they found that whereas it required a pressure load of 3,400 pounds per square inch to start cold flow in ice, the flow once started would continue under diminishing pressure down to a minimum of only 1,100 pounds per square inch. We interpret this to mean that continuous precipitation of snow on the feeding grounds of an ice-sheet would thus produce discontinuous flow at the margin, the surface alternately becoming more convex through accumulation and more flattened through ice-spread. Excess of melting likewise, since it is more rapid at the margin, increases the convexity of the surface and rejuvenates flow—a process accentuated by land uplifts accompanying ice-waning. The very melting of an ice-sheet compels a readvance. It may not be unfeasible to calculate the time factor in such an oscillation, and if this should prove near to 10,000 or 15,000 years it would harmonize these readvances of the chart much better with current estimates.

There remain also untested meteorologic and seismic cycles.

Conclusion

The purpose of this writing has been, not to solve the question of the length of glacial time, but to supply material that will some day enter into this solution—in brief, the exceedingly complicated history of glacial and post-glacial waters in the Genesee Valley, unequaled anywhere in the world. Many other elements must also enter into that solution, not the least of which will be a determination of the maximum rate of melting of the ice-sheet derived from Fairchild's study of the Susquehanna River. But, in any event, it is clear that the effort must henceforth be to harmonize the interesting clay varves with the history here shown rather than to compress this long succession of visible water-levels and attendant moraines into the brief period of time at present drawn from the varves.

Explanation of the Chart

The conventions employed in this chart are the same as in the previous one. Arrows crossing the fine vertical lines show direction of water-flow across the divides. Heavier vertical lines denote absence of drainage over

[10] "Experimental studies of ice with reference to glacier structure and motion." Zeitschrift für Gletscherkunde, vol. 9, 1915, pp. 81-139.

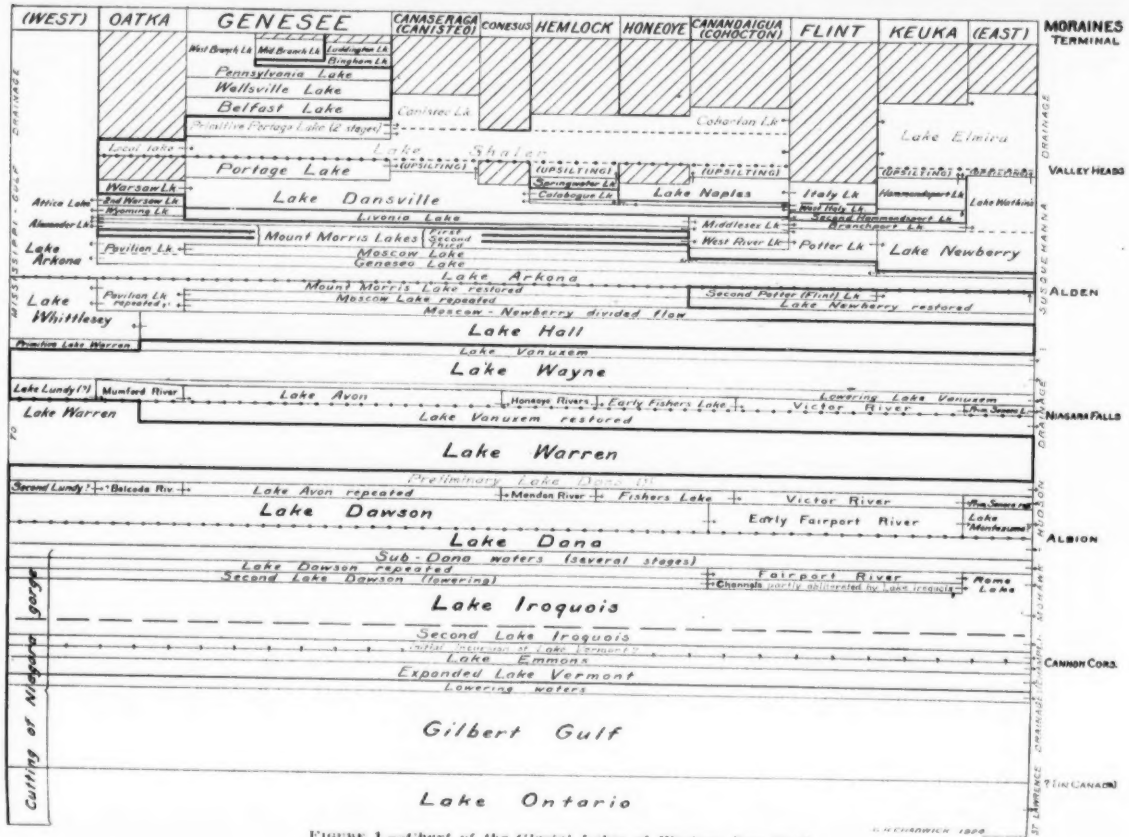

FIGURE 1.—*Chart of the Glacial Lakes of Western New York*

the divides. Heavier horizontal lines mark significant changes in direction of outlet. The heaviest black line indicates the reversals of drainage between the Mississippi and the Atlantic (Susquehanna, Hudson, Saint Lawrence). Inferred water bodies are in fainter lettering. The columns marked "west" and "east" have indefinite extent and are introduced merely to give the setting. Diagonal cross-lining signifies that the valley was still ice-filled. The ice-advances are marked by names of moraines in the right margin and by rows of dots along the horizontal lines. Most of the names of outlets have been omitted because of lack of space.

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CRITERIA AND STATUS OF CORRELATION AND CLASSIFICATION OF TERTIARY DEPOSITS[1]

PRESIDENTIAL ADDRESS BY THOMAS WAYLAND VAUGHAN

(*Delivered before the Paleontological Society December 27, 1923*)

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[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formations of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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Introduction

In the discussion for which we have met today it is intended to summarize in a very general way the information now available on the sub-

ject which forms the title of this paper, to analyze that information and the deductions based on it, and to point the way for the achievement of more satisfactory results.

Geologic correlations are effected by the comparison of geologic phenomena or events revealed through geologic phenomena in one region with geologic phenomena or events in another region in which the order of their succession in time has been standardized. Since geologic standards and comparisons with them constitute the basis of geologic correlations, the construction and utilization of such standards will be briefly summarized.

Standards in stratigraphic Geology

General statement

In stratigraphic geology the beginnings are found in single exposures or occurrences which may be concealed from view in their natural relations and are rendered visible by being brought from underground. Although a discussion of geologic standards might begin with the consideration of single occurrences of deposits, I shall first take up the lower grades of stratigraphic units and a time-scale term, namely, the terms geologic formation, member, group, and stage.

Definitions of the terms geologic formation, member, group, and stage

A geologic formation consists of a set of lithologically similar beds or of a set of beds in which there is regular or irregular alternation of dissimilar material, the entire formation having been deposited under essentially similar or recurrently similar conditions. If the beds are fossiliferous, the biologic features will exhibit no important change between the upper and lower limits of the formation. A geologic formation, therefore, is essentially similar in lithologic features and, if fossiliferous, also in its biologic features from top to bottom.

A formation may be lithologically like or unlike adjacent formations. Marked lithologic difference constitutes adequate grounds for distinguishing between two adjacent formation, as between Austin chalk and the Taylor marl, were there not also important faunal differences. There are numerous instances of adjacent formations possessing similar lithology. In such cases the distinctions are based on unconformities or disconformities, which are usually the accompaniments of marked biologic differences. An example of this kind of distinction is supplied by the Alum Bluff group and Choctawhatchee marl in western Florida, where an important erosion disconformity intervenes between the two formations, and the biologic differences are very marked.

In certain parts of the area underlain by a geologic formation there may be present within the formation a bed or beds of sufficiently distinctive features to warrant the application of a name subordinate in rank to that of formation. Such constituents of formations are designated members.

Successive formations may possess certain general lithologic or biologic features in common which render it desirable to combine several formations into a group. For example, the lowest three Eocene formations in Alabama—the Clayton formation, the Sucarnochee clay, and the Naheola formation—constitute the Midway group. Several other formations constitute the Wilcox and Claiborne groups of the Eocene.

The geologic subdivisions mentioned above are solely stratigraphic—that is, they are for masses of earth which possess length, breadth, and thickness, notwithstanding the fact that the stratigraphic units may be biologically as well as lithologically characterized. In geologic thinking there is a time concept as well as the concept of dimension, and it is easy to pass from the dimensional to the time concept, because the deposition of the material composing the bed, member, formation, or group required time. The passage from the volumetric to the time concept is usually indicated by placing the adjective ending *an* or *ian* after the stratigraphic designation. For the major subdivisions of the Eocene in the southern United States the names Midwayan, Wilcoxian, Claibornian, and Jacksonian would indicate the time during which each corresponding stratigraphic unit was deposited. Although these terms have not been formally adopted in America, they have gradually attained rather wide usage.

The stage names for Tertiary time current in Europe are the adjective forms of the stratigraphic terms for the major subdivisions of the different series which compose the Tertiary system in Europe—for example, Calcaire de Mons is the basis of the name Montian, and the Thanet sand, of Thanetian. Thanetian means not Thanet sand, but the time of the deposition of the Thanet sand.

TYPE LOCALITIES OF STRATIGRAPHIC UNITS

It is hoped that the preceding remarks have made it clear that the stratigraphic divisions or units of the different grades are physical entities, and that the time or stage name is the time equivalent of the epoch during which the corresponding stratigraphic unit was deposited. In order to be sure that any stratigraphic or chronologic term is correctly applied, there must be for each stratigraphic unit a standard occurrence the validity of which is not subject to doubt. The locality at which

a stratigraphic unit is typically represented—that is, the type locality of the unit—is determined by designation.

When the science of geology was young and stratigraphic classification was not so precise as now, the need of the designation of type localities was not so clearly recognized as at present, and therefore the authors of geologic terms were not always particular to say precisely where the geologic subdivision described was typically represented. In the case of some old terms, the type localities need to be determined by inference from the descriptions. Now, however, a geologist who does not designate the type locality of a stratigraphic unit is guilty of a reprehensible act. As geologic research has advanced, it has been generally recognized among stratigraphic geologists that type localities are as necessary for the nomenclature of stratigraphic geology as type specimens of species are for biologic nomenclature.

The earliest date at which geographic names were applied to stratigraphic units is not certainly known, but numbers of the pioneer geologists adopted the practice. One of the oldest geographic names applied to a formation is that of the London clay, which was used by Conybeare and Phillips in 1822.[2] They say:

> "Its name is derived from its forming the general substratum of London and its vicinity, occurring immediately beneath the vegetable soil, excepting when occasional deposits of alluvial or diluvial gravel, sand, etc., intervene."

In the first edition of Lyell's "Principles of Geology" there are several geographic names, such as Bagshot sand, Hastings sands, Maestricht beds, and Weald clay. Lyell, however, was inclined toward a chronologic rather than toward a geographic and stratigraphic nomenclature. D'Orbigny introduced the terms Suessonian and Parisian for divisions of the Tertiary and defined them well.

STANDARD STRATIGRAPHIC SECTIONS AND GEOLOGIC TIME-SCALES

The primary principle employed in the construction of a standard stratigraphic section and geologic time-scale is the order of superposition of the different rock layers. The determination of the order of succession of the different strata of rocks is not always easy, because, as all field geologists know, all the different stratigraphic subdivisions are not only not found in their proper order in any one place, but they are not found in any dozen places. Stratigraphic columns, therefore, are constructed by putting together exposures at many localities. In order to construct

[2] W. D. Conybeare and W. Phillips: Outlines of the geology of England and Wales, 1822, p. 23.

an entirely reliable section, there must be no error in the fitting together of the many separate exposures. This, of course, can be done; but there is probability of error and usually many trials have to be made before a completely trustworthy result is obtained. Later a succinct statement will be made regarding the sections of the American Tertiary formations.

Before a carefully worked out section can be widely utilized for correlation purposes, each stratigraphic unit of which it is composed needs to be biologically characterized, or the biologic features of the time unit corresponding to the stratigraphic unit need to be ascertained in some way. The faunas and floras of stratigraphic units are usually not comprehensive at any one place. Therefore, in order to discover the biologic features of the time represented by stratigraphic units, marine and terrestrial deposits must be found where they exhibit interbedding—that is, marine beds must be traced along their strike until they merge into terrestrial deposits, or *vice versa*. To discover the biologic features of the different geologic epochs is a difficult task, and, as it must be done by shifting from one place to another, probability of error is introduced. Subsequently the degree of completeness and the dependability of the biologic characterization of some of the Tertiary formations in America will be briefly described and comments will be made on the biologic characterization of some of the divisions of the Tertiary in Europe.

Methods of geologic Correlation

The different methods of geologic correlation

There are at least six usable criteria for geologic correlation, which are as follows: (1) By actually tracing geologic formations from one place to another; (2) by lithologic peculiarities and the succession of associated beds; (3) by diastrophic history; (4) by physiographic history; (5) by climatic history; (6) by biologic features.

The criteria numbered 1 to 5 are of great value in local or even regional correlation, but numbers 1 to 4 can not be used in correlating between geologic formations on opposite sides of the Atlantic Ocean, and the validity of number 5 is doubtful. Therefore major, if not sole, dependence must be for the present placed on number 6, namely, biologic features.

The biologic methods

General statement.—The two well-known methods of correlating Tertiary formations by their biologic features are the Lyellian method of ascertaining the percentage of Recent species in the fauna and by inference from the known stratigraphic ranges in standard sections.

The Lyellian method and its defects.—The Lyellian method is based on two assumptions: One of which is that the standard of the discrimination of species of mollusks by Deshayes will be the standard of other workers, and the other is that the rate of organic change is the same for all parts of the earth. Both of these assumptions seem to be erroneous.

Unanimity of treatment of the species of the different groups of organisms has not been attained, and it may be rather confidently predicted that it never will be. Perhaps an exception should be made in favor of the birds of North America. The lamentations over changing names will probably continue indefinitely, because they are merely reaction against progress. Systematic biology, including biologic taxonomy, has as its fundamental purpose the expression of what is thought to be the reciprocal relations and degrees of kinship between the different groups of organisms. Since the opinions of today on these matters may differ significantly from the opinions of yesterday, the ideas held yesterday need revision. Systematic biology, therefore, if we advance in knowledge of organisms, must always be in a state of unstable equilibrium, for stable equilibrium would signify that advance in knowledge has ceased.

Discrimination between species, so called, is now much finer than in the days of Lyell and Deshayes, and now about the same percentage of Recent species is recognized in deposits of older Miocene age (Langhian)[3] that Lyell considered characteristic of the Eocene.

The second assumption of the Lyellian method, namely, that the rate of organic change is the same for all parts of the earth, will now be briefly considered. I will first mention that a considerable number of genera of organisms found in deposits of Eocene to Miocene age in the Atlantic region are now extinct there, but they are still living in the Indo-Pacific region; and that some of the Tertiary species of the Atlantic region are represented by closely related species living in Indo-Pacific region, but there are no closely related species living in the Atlantic.[4] The groups of organisms that exhibit these relations are the coralline algæ, foraminifera, corals, echinoids, mollusks, and crustacea. With regard to the rate of specific change in the Pacific I will quote from a translation I have made of a paper by Prof. K. Martin:[5]

"That I designate as Miocene sediments which contain 45 per cent of living mollusks may raise doubt, especially when this estimated percentage, for rea-

[3] Julia Gardiner, cited in T. W. Vaughan's On the relative value of species of smaller Foraminifera for the recognition of stratigraphic zones. Amer. Assoc. Petroleum Geologists Bull., vol. 7, 1923, p. 522.

[4] T. W. Vaughan: Correlation of the Tertiary formations of Central America and the West Indies. First Pan-Pacific Sci. Conference Proc., pt. 3, 1921, pp. 819-821.

[5] K. Martin: Unsere palæozoologische Kenntnis von Java, 1919, pp. 32-33; translation by T. W. Vaughan. 1st Pan-Pacific Sci. Conference Proc., pt. 3, 1921, p. 763.

sons already stated, is appreciably below the real percentage. In reply to this it is to be emphasized that *in similar Neogene sediments of Europe and the Indies the deposits in the latter region must contain a higher percentage of living species than the former.* This is because there were during the Tertiary time important climatic changes in the extra-tropical regions, while no such changes took place in the tropics. In the tropics, accordingly, there were fewer factors which would modify the species and, therefore, the transformation of the fauna in the tropics did not take place so rapidly as in our [European] region, and, consequently, more species have persisted until the present time. The younger the strata are, the larger must be the difference in percentage for equivalent strata in Europe and the Indies; precise values for these can not be given."

P. Marshall says regarding New Zealand:[6]

"The percentage of Recent species does not give a satisfactory basis for a comparison with European horizons. The isolation of New Zealand and the relatively rare arrival of species from outside the New Zealand area make it probable that species would survive for a much longer time here than on coastlines where there was more competition from newly arrived species. It is probable that a fauna in New Zealand with 20 per cent of Recent species would have a much greater antiquity than a fauna with a similar percentage of Recent species in Europe or America."

The opinion has become prevalent among paleontologists that organic change has been less rapid in the Pacific than in the Atlantic, and that the Lyellian method of determining the relative ages of strata by the percentage of Recent species of mollusks is not equally applicable everywhere.[7]

Although the percentage method should not be given implicit confidence, it should be utilized, because if certain precautions are taken it does give an indication of the degree of similarity between the faunas that are compared one with another. The differences between contemporaneous faunas of different ecologic associations should be kept in mind. Recently I have pointed out that, in a section from a lagoon of the Cocos-Keeling Islands across the reef rim, only 13 per cent of the lagoon species occur on the exposed barrier and only 18 per cent of the species on the exposed barrier occur in the lagoon.[8] The order of difference between the two faunas is the same as that between Recent and older Miocene or late Oligocene. Unless the entire faunas of epochs are available for com-

[6] P. Marshall: The Tertiary molluscan fauna of Pakaurangi Point, Kaipara Harbour. New Zealand Inst. Trans., vol. 50, 1918, p. 276.

[7] Compare with these statements the discussion of the same problem from the standpoint of vertebrate paleontology by W. D. Matthew: Climate and evolution. N. Y. Acad. Sci. Ann., vol. 24, 1915, p. 171.

[8] T. W. Vaughan: U. S. Nat. Mus. Bull. 103, 1919, p. 192.

parison, comparisons should be made only between those that lived under similar ecologic conditions.

Characteristic forms and probable error from their use.—The second method of correlation by biologic features is by a study of the stratigraphic ranges of the different genera and species composing a fauna. The basis for correlation by this method is laid in the study of the successive faunas or floras of some section adopted as a type, for which the stratigraphic range of each species is determined with as much precision as is possible. In this way the species of wide range and those of restricted range are separated from one another and the relative value of each species for correlation purposes is ascertained. It has been pointed out by many paleontologists that the more complex the structural features of an organism are, the more restricted will be its stratigraphic range. This is the principle that underlies the high value of mammals for correlation purposes. The range of species of mollusks, brachiopods, and other organisms that possess surface sculpture will be inversely proportional to the degree and complexity of the surface ornamentation; and the value of the larger Foraminifera, such as *Discocylina*, *Asterocites* and *Lepidocyclina*, in the identification of stratigraphic horizons is a result of complex, mostly internal, structure.

If the stratigraphic ranges of the different species and higher groups of organisms were accurately known, correlation would depend merely on the accurate identification of the fossils found in any deposit whose correlation is desired; but the possession of so complete knowledge is doubtful. The field geologist is continually finding that species and genera have wider ranges than was supposed, and consequently he may have to change his opinion regarding the age or stratigraphic equivalence of some deposit. The conclusions regarding the age of formations with reference to other formations are, therefore, only probably correct; but, by careful study and the accumulation of a large body of evidence, the degree of probability that the conclusions are correct may be very high for a specific region.

Another serious obstacle in the way of making the application of specific and generic ranges as determined in one region world wide arises from the fact that organisms are not free to migrate to all parts of the earth at any one time. In the sea there are land barriers, such as the American and the Afrieo-Eurasiatic continents between the Atlantic and Indo-Pacific oceans, and the distribution of marine organisms is also affected by differences in the temperature and the depth of the water. Although the Atlantic and Pacific oceans connect with each other south of South America, the tropical organisms of neither ocean can pass to

the other, even though they may be pelagic at some stage of their life, for the water is too cold where the oceans communicate. The tropical organisms of the two oceans are, therefore, confined and have been so restricted geographically for considerable time. Water and climatic differences restrict terrestrial organisms in a manner comparable to the way in which land and marine temperatures restrict marine organisms. Therefore organisms usually are geographically restricted in their ranges, and those of one area are not suited for comparison with those of another area in which they do not occur.

Another factor in determining the value of organisms in problems of correlation is the rate of dispersal over regions across which there are no unsurmountable barriers. Some organisms—mostly terrestrial mammals, for instance—can move rapidly and, geologically considered, can occupy nearly the whole extent of a possible geographic range simultaneously. A horse can easily travel the distance from the Atlantic to the Pacific side of the United States within about six months. In fact, the capacity of terrestrial mammals for rapid locomotion is one of the factors that renders them of so high value for correlation purposes. Some of the marine mammals, especially the Cetacea, also can move rapidly over long distances and, therefore, are capable of greatly assisting in correlation between continents, as between northern eastern Asia and northern western America and between northern eastern America and northern western Europe. Plants, especially those whose seeds are carried by the wind, may be rapidly distributed.

In the sea there are, besides the Cetacea, organisms that may be widely distributed within a relatively short time: they are the pelagic organisms, both those, such as the fishes, that move because of their own exertions and those that are carried by ocean currents, such as the pelagic Foraminifera. Unfortunately, marine fishes, except sharks, are rare as identifiable fossils and the pelagic Foraminifera are stratigraphically so wide-ranging that they are of small value for general correlation purposes. Most of the marine organisms which are available for use in geologic correlation are either sedentary or move very slowly in their adult life. This statement applies to most of the Foraminifera, corals, echinoids, most Bryozoa, and most mollusks. The members of at least several of these groups of organisms, however, pass through free-swimming larval stages, and, as the major agency that will cause dispersal is ocean currents, it is of vital importance to know both the duration of the free-swimming larval stage of members of each group of organisms and the system of ocean currents of each geologic epoch. Unfortunately, information on both of these subjects is meager.

The alternation of generations in many Foraminifera is well known, but the capacity of the young, especially after the subdivision of the macrospheric parent, to be transported by ocean currents before becoming bottom-living organisms is either not known or the information is not widespread. Many species of Foraminifera are widely distributed, there being a large number of species common to the living faunas of both the Atlantic and the Pacific. These species also have great stratigraphic range, having existed since the Miocene or even an older epoch, and therefore have had a long time in which to attain their present distribution. Just how this distribution has been attained is not known.

The means whereby the bottom-living Foraminifera are distributed geographically is of great importance to geologists. To make this clear, a few notes will be made on some of the larger genera. The large species of the true *Nummulites,* such as those represented by *N. lævigatus, N. obtusus, N. gizehensis,* and *N. aturicus,* extend from western Europe eastward to the Bonin Islands, but the group has not yet been found in America. It looks as though these organisms could not pass a great expanse of ocean, even if the ocean currents were favorable. On the other hand, *Operculina, Discocyclina, Asteriacites,* and *Lepidocyclina* are found all around the world, where the climatic conditions were favorable, although their stratigraphic distribution is not the same in all places. The four genera mentioned obviously possess a capacity for distribution beyond that of *Nummulites.*

The duration of the free-swimming larval stages of some corals has been ascertained by me. For the species studied the duration may range from a few days to as much as three weeks.[9] Wide distribution by marine currents is obviously possible, if there are landing places along the course of the currents. That the distribution of some species of corals is wide is shown by the presence of the same species of corals on the east coast of Africa and in the Hawaiian Islands, and by the presence of very similar corals in the Rupelian Oligocene at numerous places in northern Italy and in the lower part of the Antigua formation of Antigua, West Indies, and at a similar horizon elsewhere in America.

The echinoids have a pelagic larval stage, but I am not aware that the duration of the larval stage has been studied with reference to the possible distribution of species by ocean currents.

Bryozoa, also, have a free-swimming larval stage, but the number of observations on the duration of the stage is limited. Dr. R. S. Bassler informs me that for those species on which observations have been made

[9] T. W. Vaughan: Carnegie Inst. Washington Yearbook No. 9, 1911, p. 144; Nat. Acad. Sci. Proc., vol. 2, 1916, p. 99; Smithsonian Inst. Ann. Rept. for 1917, 1919, p. 210.

the duration of the free-swimming stage is measurable in relatively few hours.

Many mollusks pass through a free-swimming larval stage and are, therefore, capable of distribution by ocean currents, but I do not know of any attempt to assemble the available data bearing on the duration of that stage.

It needs also to be mentioned that sedentary organisms may become attached to floating objects, such as driftwood and pumice, and be transported by currents from one place to another.

If an attempt is made to compare a Tertiary fauna of Italy, for instance, with a Tertiary fauna of the corresponding climatic zone in America, one of the first steps should be to find out what organisms could get from one region to the other and how they could make the journey. The rate at which the journey could be made would depend on the means by which it was made. One of the biologic desiderata for geologic purposes is a more thorough understanding of the means of distribution of organisms, and to supply these desiderata more comprehensive investigations of the free-swimming larval stages of the several groups of marine organisms are essential. Until this subject is better understood, many of the results derived from comparing faunas from distant regions must be of uncertain validity and, therefore, only tentative.

The foregoing remarks have indicated certain defects in both the Lyellian method of correlation and in deductions based on the assumption of known stratigraphic distribution of genera and species; but it will now be shown that by combining the evidence of organisms of different habitats it may be possible to reach more satisfactory conclusions.

The presence of similar marine invertebrate faunas in deposits in Europe and America may not be considered sufficient evidence to establish the synchroneity of the deposits, but if the marine faunas are interbedded with deposits containing terrestrial organisms, the terrestrial organisms may be used as checks on the marine. During Tertiary time there were numerous opportunities for the intermigration of land animals and plants between Eurasia and North America, and fortunately for geologists at many places fossiliferous terrestrial and marine deposits are interbedded and both kinds of organisms have been studied. Dr. W. D. Matthew has given an able account of the interchanges of terrestrial mammals between the two continents in his memoir, "Climate and evolution";[10] Prof. E. W. Berry has discussed the interrelations of the Tertiary floras of Europe and eastern North America, and Dr. Remington Kellogg has rendered valuable aid in the correlation of American Tertiary formations

[10] N. Y. Acad. Sci. Ann., vol. 24, 1915, pp. 171-318.

through his studies of the fossil Cetacea of the Coastal Plain of the United States. We are to be congratulated that we have the results of each of these investigators for the present discussion. The value of terrestrial and pelagic mammals for geologic correlation has already been indicated. Fossil plants are scarcely so delicate indicators of time equivalence as the mammals, but they yield valuable evidence and have given useful checks on the marine invertebrates.

Previous Attempts to correlate American with European Tertiary Formations

General statement

It is not practicable to review here all the attempts at the correlation of American with European Tertiary formations, because to do so would require a moderate-sized volume. The early American geologists began immediately to try to ascertain the time relations of the American formations in terms of the European subdivisions of the Tertiary. Conrad[11] in 1832 presented a general correlation table for the Tertiary formations of the eastern and southeastern part of the United States, and, considering the time at which it was made, it is good. Isaac Lea[12] in 1833 discussed the subject and in essentials expressed opinions similar to those of Conrad. Since those early days there has been an unbroken series of efforts to correlate the American Tertiary formations. An account of the efforts up to 1891 on the correlation of the Eocene and the post-Eocene formations is given by W. B. Clark[13] and by W. H. Dall and G. D. Harris[14] in the papers cited below. A few years later G. D. Harris contributed to the fourth edition of Dana's Manual of Geology,[15] most of the text dealing with the Tertiary formations. W. H. Dall is the author of a highly important paper entitled "A table of North American Tertiary horizons, correlated with one another and with those of western Europe, with annotations."[16] Other papers that deserve mention are Dr. Carlotta J. Maury's "A comparison of the Oligocene of western Europe and the southern United States";[17] Dr. W. H. Dall's "Geological results of the study of the Tertiary fauna of Florida";[18] and his "The

[11] T. A. Conrad: Fossil shells of the Tertiary formations of North America. Introduction, pp. 9-10.

[12] I. Lea: Contributions to geology. Introduction, pp. 18-21.

[13] W. B. Clark: Correlation papers. Eocene. U. S. Geol. Survey Bull. 83, 1891, p. 173.

[14] W. H. Dall and G. D. Harris: Correlation papers. Neocene. U. S. Geol. Survey Bull. 84, 1892, p. 349.

[15] See supp., 1895, pp. 879-927.

[16] U. S. Geol. Survey 18th Ann. Rept., pt. 2, 1898, pp. 323-348.

[17] Amer. Paleontol. Bull., vol. 3, 1902, pp. 311-404.

[18] Wagner Free Inst. of Sci., Phila., vol. 3, pt. 6, 1903, pp. 1541-1620.

relations of the Miocene of Maryland to that of other regions and to the Recent fauna." [19]

Recently a number of other papers have been published, especially by E. W. Berry, C. J. Maury, H. Douvillé, C. A. Matley, R. T. Trechmann, C. W. Cooke, W. P. Woodring, and me. As the titles of most of the papers by the other authors are given in my papers, I will merely list in the footnotes below some of the most recent publications and my later papers, in which references to earlier papers are given.[20]

The publications mentioned or referred to above do not consider in any general way the horizons of American fossil vertebrates. Since it is important that they also should be taken into account, attention will be

[19] Maryland Geol. Survey, Miocene, 1904, pp. cxxxix-clv.

[20] C. W. Cooke: The correlation of the Vicksburg group. U. S. Geol. Survey Prof. Paper 133, 1923, pp. 1-9.

H. Douvillé: Revision des Lépidocyclines. Soc. Géol. France, Mém., N. S., no. 2, 49 pp., 2 pls., 47 text figs., 1924.

K. W. Earle: Report on the geology of Antigua. 28 pp. Govt. Printing Office, Antigua, 1923. (Bibliography.)

H. G. Kugler: Das Eozänprofil von Soldado Rock bei Trinidad. Eclogæ geolog. Helvet., vol. 18, 1923, pp. 253-259.

C. A. Matley: Some recent contributions to the geology of Jamaica, with a bibliography. Handbook of Jamaica, 1923, 15 pp., Govt. Printing Office, Kingston, Jamaica, 1923.

C. A. Matley: Report on the work of the Government geologist and on the progress of the geological surveys in Jamaica for economic purposes. Jamaica Gazette, Supplement, vol. 46, 1923, pp. 225-231.

C. A. Matley: Report of the Government geologist on the progress of the geological surveys in Jamaica in connection with its water resources, for the period June, 1923, to April, 1924. Ibid., vol. 47, 1924, pp. 45-48.

C. A. Matley: Report of a reconnaissance geological survey of the Cayman Islands. Ibid., vol. 47, 1924, pp. 69-73.

C. A. Matley: Recent geological work in Jamaica. Abstract of paper presented at Brit. Assoc. Adv. Sci., Toronto meeting, 1924.

A. Olsson: The Miocene of northern Costa Rica, with notes on its general stratigraphic relations. Amer. Paleontol. Bull., vol. 9, 1922, pp. 174-482, pls. 4-35.

L. Rutten: Cuba, the Antilles, and the southern Molluccas. Kon. Akad. Wetensch. Amsterdam Proc., vol. 25, 1922, pp. 263-274, 1 pl.

L. Tobler: Die Jacksonstufe (Priabonien) in Venezuela und Trinidad. Eclogæ gelog. Helvet., vol. 17, 1922, pp. 342-346, pl. 19.

C. T. Trechmann: The Cretaceous and Tertiary question in Jamaica. Geol. Mag., vol. 59, 1922, pp. 422-431.

C. T. Trechmann: The Barettia beds of Jamaica. Ibid., vol. 59, 1922, pp. 501-514, pls. 18-20.

C. T. Trechmann: The Yellow limestone of Jamaica and its mollusca. Ibid., vol. 60, 1923, pp. 337-367, pls. 14-18.

T. W. Vaughan: Correlation of the Tertiary geologic formations of the southeastern United States, Central America, and the West Indies. Washington Acad. Sci. Jour., vol. 8, 1918, pp. 268-276.

T. W. Vaughan: Geologic history of Central America and the West Indies during Cenozoic time. Geol. Soc. Amer. Bull., vol. 29, 1919, pp. 615-630.

T. W. Vaughan: Fossil corals from Central America, Cuba, and Porto Rico, with an account of American Tertiary, Pleistocene, and Recent coral reefs. U. S. Nat. Mus. Bull. 103, 1919, pp. 189-524, pls. 68-152, text figs. 4-25.

called to the investigations of Prof. H. F. Osborn.[21] As has already been pointed out in this address, the evidence of both the marine and terrestrial animals needs to be brought to bear on the correlation of the American Tertiary formations.

SOME DEFECTS OF THE PREVIOUS ATTEMPTS AND SUGGESTIONS FOR REMEDYING THEM

The principal reasons for the defects in the earlier, as well as in the present, treatment of this subject is inadequate information—a condition due to several causes, some of which could scarcely have been obviated. Knowledge of the stratigraphy and paleontology of both the European and American Tertiary formation has required great labor, extending over a long time. It is interesting to take some old book, such as Lamarck's "Système des Animaux sans Vertèbres," and count the number of names of familiar Tertiary fossils and notice the references to earlier literature. For considerably more than a century earnest attention has been devoted to this subject in Europe. Maclure's "Observations on the Geology of the United States" appeared in 1809, and before 1830 a number of papers on the paleontology and general relations of the Tertiary formations in America had been published. In the United States there

T. W. Vaughan: The biologic character and geologic correlation of the sedimentary formations of Panama in their relation to the geologic history of Central America and the West Indies. U. S. Nat. Mus. Bull. 103, 1919, pp. 547-612.

T. W. Vaughan: Correlation of the Tertiary formations of Central America and the West Indies. First Pan-Pacific Scientific Conference Proc. Correlations of post-Cretaceous formations in the Pacific region, 1921, pp. 819-844. (Bibliography.)

T. W. Vaughan: The stratigraphic significance of the species of West Indian fossil echinoids. Carnegie Inst. Washington Pub. 306, 1922, pp. 105-122.

T. W. Vaughan: Studies of larger Tertiary Foraminifera from tropical and subtropical America. Nat. Acad. Sci. Proc., vol. 9, 1923, pp. 253-257.

T. W. Vaughan: The stratigraphy of the Virgin Islands of the United States and Culebra and Vieques Islands and notes on eastern Porto Rico. Washington Acad. Sci. Jour., vol. 13, 1923, pp. 303-317. (Bibliography.)

T. W. Vaughan: Recent additions to knowledge of the correlations of the Tertiary geologic formations of northeastern Mexico, Central America, the West Indies, northern South America, and Lower California. Second Pan-Pacific Science Congress proc. (in press, November 1, 1923).

W. P. Woodring, J. S. Brown, and W. S. Burbank: Geology of the Republic of Haiti. Repub. Haiti Geol. Survey 1924, 631 pp., 40 pls., 37 text figs. (Bibliography.)

[21] H. F. Osborn: Correlation between the Tertiary mammal horizons of Europe and America. N. Y. Acad. Sci. Ann., vol. 13, 1900, pp. 1-72.

H. F. Osborn: Cenozoic mammal horizons of western North America, with faunal lists of the Tertiary Mammalia of the West, by William Diller Matthew. U. S. Geol. Survey Bull. 361, 1909, p. 138.

H. F. Osborn: Correlation of the Cenozoic through its mammalian life. Jour. Geol., vol. 18, 1910, pp. 201-215.

H. F. Osborn: Correlation and paleogeography. Geol. Soc. Amer. Bull., vol. 23, 1912, pp. 232-256.

References to other papers on correlation by Professor Osborn may be found in the bibliography of his published writings.

has been unremitting effort for more than 100 years to acquire information on the Tertiary geology of the country. It would be unreasonable to expect that the successive investigators would withhold opinions on the probable age relations of the fossils they were studying until knowledge might be supposedly complete and they did express opinions which it must be recognized were to be regarded as only tentative. However, the attempts at correlation were helpful and it is gratifying to note that some correlations made nearly 100 years ago were substantially correct; for instance, the correlation by Conrad and Lea of the fauna of the "Claiborne sands" of Claiborne, Alabama, now known as the Gosport sand, with the Calcaire grossier, the Lutetian, of the Paris basin. It now seems that the Gosport sand is the equivalent of the Auversian, but Conrad and Lea were nearly right.

One reason that knowledge of the interrelations of the American and European geologic formations has not grown more rapidly is due to the fact that so few Americans have made field studies in Europe, and consequently have no or only meager first-hand knowledge of the stratigraphic relations of the European formations. I do not know of any American geologist who is personally familiar with the Tertiary formations in southwestern France and northern Italy. Although a number of European geologists have discussed American Tertiary formations, I do not know of any living European geologist who has any comprehensive first-hand knowledge of the American Tertiary formations. Some European geologists have had limited experience in some of the West Indies; others have seen parts of Central America; others something of Mexico; others parts of South America, and a few have seen something of as much as two of these regions. I do not know any European geologist who has any first-hand knowledge of the splendid sections of Tertiary deposits to be seen in the Coastal Plain of the United States. As I am American, I naturally detect defects in discussions by Europeans; perhaps Europeans detect similar failure to understand European conditions on the part of Americans who discuss European formations. One of the means for advancing the correlations of the American Tertiary formations is for the American geologists to make field studies of the Tertiary formations of Europe, and for the Europeans to make field studies of the Tertiary formations in America. The museums in the different countries are not utilized to the extent they should be.

Another cause of many unsatisfactory discussions is lack of knowledge of the literature published in countries other than one's own. To master the literature on a region with which one has only slight personal familiarity is tedious and difficult, but the feat can be accomplished. Some

Europeans seem to have mastered the needed American literature, but others have not done this, and consequently commit serious blunders. Some know of the existence of literature and may even give lists of publications which they obviously have not read. Some of the errors indicated above might have been avoided by applying to specialists in the fields on which information was needed. The lack of knowledge of the literature published in different countries is closely related to lack of contact between the workers in the different countries. Problems of international scope require more than a provincial view and provincial personal contacts. One means of advancing in the study of correlation problems is for the investigators in the different countries cultivating as close personal relations as may be possible.

For the further advance in the correlation of American Tertiary formations the first desideratum is additional paleontologic work. Professor Berry has done a monumental piece of work in the set of monographs he has prepared on the Tertiary floras of the Atlantic and Gulf Coastal Plain, and he has done something toward making known the fossil floras of Mexico, Central America, and the West Indies. Dr. M. A. Howe has published several important papers on the fossil calcareous algæ of Panama and the West Indies. Until more material has been collected, further work on the fossil plants of the Coastal Plain is not now necessary, but knowledge of the fossil floras of Central America and the West Indies is very meager and efforts should be made to procure more extensive collections.

Doctor Cushman has published several papers on the larger Foraminifera, Doctor Tobler has published two papers, Doctor Woodring and I have each published one paper, and I have other papers ready or about ready for press. H. Douvillé has also published several papers, but some of his stratigraphic data are wrong. Although considerable is known regarding the larger Foraminifera, much more work is needed. Some of the deficiencies will be more clearly indicated later in this discussion.

With reference to the smaller Foraminifera some information is already available in publications by Doctor Cushman, and other papers by him may be expected. Although the smaller Foraminifera may be serviceable in local correlation, and therefore should be studied, the range of the species, according to available information, is too great for regional or intercontinental purposes. I have recently discussed this subject in the article cited below.[22]

[22] T. W. Vaughan: On the relative value of species of smaller Foraminifera for the recognition of stratigraphic zones. Assoc. American Petroleum Geologists Bull., vol. 7, 1923, pp. 517-530.

Knowledge of the fossil coral faunas of the Oligocene of Georgia and Florida and of the Miocene and Pliocene of Florida is insufficient. Although considerable is known of the Tertiary corals of the West Indies and Central America, much more work needs to be done.

The Tertiary echinoids of the Coastal Plain, Central America, and the West Indies are now fairly well known through the recent efforts of Messrs. Clark and Twitchell, Doctor C. W. Cooke, Doctor Jackson, and Professor Hawkins, and an additional paper by Doctor Jackson may soon be expected.

The Tertiary Bryozoa of the Coastal Plain, the West Indies, and parts of Central America have been made known by Canu and Bassler, but additional studies of the Central American species are needed.

The Tertiary mollusks of the Coastal Plain will be known with considerable comprehensiveness as soon as Prof. G. D. Harris publishes his studies of the gastropods of the Claiborne group, Doctor C. W. Cooke his of the Jackson and Oligocene mollusks, and Doctor Julia Gardner hers of the Miocene and Pliocene of Virginia and North Carolina, the Alum Bluff Miocene of Georgia and Florida, and the Eocene of Texas. Mr. W. C. Mansfield has completed a study, not yet published, of some of the Miocene mollusks of Virginia. The deficiencies that remain are the Miocene faunas of South Carolina and the Choctawhatchee marl of Florida. Although considerable work has recently been done on the West Indian and Central American fossil mollusks by Messrs. Toula, Pilsbry and A. P. Brown, Dr. C. W. Cooke, Dr. C. J. Maury, Dr. Bela Hubbard, Dr. C. T. Trechmann, Dr. W. P. Woodring, and Dr. Axel Olsson, and other studies are in progress, knowledge of the fossil mollusks of the Caribbean region is far from adequate. There are in the United States National Museum enormous collections of fossils from Costa Rica, Panama, Colombia, and the Dominican and Haitian republics awaiting detailed investigations. The adequate description of these collections and the publication of the results are, perhaps, the most outstanding desiderata in the study of the marine Tertiary formations of America.

The studies of Dr. M. J. Rathbun and Dr. H. A. Pilsbry have given us a fairly good knowledge of the fossil Crustacea of the Caribbean region, but information is deficient on the Crustacea of the Coastal Plain.

With reference to the fossil vertebrates of the Coastal Plain and the Caribbean region, I will only say that knowledge of them is extremely meager and earnest endeavors should be made to procure more information.

Further knowledge of the Tertiary stratigraphy of most of the Caribbean region is sorely needed. Great assistance would be rendered if the

large amount of data acquired by geologists in Costa Rica, Panama, Colombia, Venezuela, and Cuba could be prepared for publication. Additional geologic surveys are needed for Cuba, the Dominican Republic, some of the smaller West Indian Islands, parts of Mexico, Guatemala, Nicaragua, and Costa Rica, and visits should be made to other Central American countries and to some West Indian islands on which considerable information is already available.

Attention has so far been paid only to suggestions regarding work in America. Some biologic groups of European fossils need to be monographically studied by competent experts. I will particularly mention the corals. Recent experiences I have had with European Tertiary corals show that many of the species are referred not only to the wrong genera, but to the wrong families, and the generic nomenclature is very faulty. The fossils need to be critically revised by a paleontologist who has a comprehensive knowledge of corals, both living and fossils; he should bear in mind that generic identifications, to be valid, must be based on the type species of the genus, and the nomenclature he adopts should conform to the International Rules of Zoological Nomenclature.[23] The nomenclature of the larger Foraminifera is in a chaotic state because of the failure of prominent students of these organisms to conform to the standard rules of zoological nomenclature.

Besides systematic revision of groups, such as those indicated above, there is urgent need for systematic lists of the different biologic groups of European fossils, with precise indications of the stratigraphic ranges of the different species, particularly of the species known in standard or standardized stratigraphic sections. At present it is impracticable to make comprehensive and exact comparison of the Tertiary faunas of foreign lands with those of Europe. It is hoped that European stratigraphic paleontologists will endeavor to prepare lists of the kind indicated.

The suggestions for advance in the solution of problems of the correlation of the American Tertiary formations need to be summarized. They are as follows: (1) Field studies of European Tertiary formations by American geologists and of American Tertiary formations by European geologists; (2) studies in European museums by Americans and in American museums by Europeans; (3) more comprehensive and careful studies of European literature by American geologists and of American literature by European geologists; (4) the cultivation of closer personal relations between European and American geologists by the exchange of publications and the exchange of views through correspondence; (5)

[23] See Ninth Internat. Zool. Cong. Proc., Monaco, 1913.

additional studies of American Tertiary fossils, namely, the floras of Central America and the West Indies; the larger Foraminifera; the corals, especially of the West Indies; Central American and West Indian mollusks; Coastal Plain, Central American, and West Indian vertebrates; (6) publication of available stratigraphic information on Costa Rica, Panama, Colombia, Venezuela, Cuba, and parts of Mexico; (7) additional geologic surveys in Cuba, the Dominican Republic, some of the smaller West Indian islands, parts of Mexico, Guatemala, Nicaragua, and Costa Rica, and visits to other Central American countries and some West Indian islands on which considerable information is already available; (8) European paleontologists are asked to supply critical revisions of some of the biologic groups of fossils, of which the corals and the larger Foraminifera are specified, and to supply for all groups of fossils critically prepared lists on which will be shown the stratigraphic ranges of all the species.

Importance of the Study of the American Tertiary Formations

The correlation of the Tertiary formation of the Coastal Plain of the United States is important, both as an end in itself and as a stepping stone to other things. As an end in itself, it is desirable to know the ages of the formations in terms of the European time equivalents. As a stepping stone to other things, the Coastal Plain of the United States, except its southeastern corner, was climatically analogous during Tertiary time, as it is at the present time, to middle western Europe, and the biotas of the division of the Tertiary are analogous in the two regions. In the southeastern corner of the Coastal Plain there are interdigitations of temperate and tropical water faunas and opportunity is afforded to discover something of the contemporaneous faunas of different climatic zones during Tertiary time. By means of the Coastal Plain faunas it is possible to step from temperate to tropical faunas, both for America and for Europe. Of course, in Europe there are also opportunities to discover the contemporaneous faunas in different climatic zones; but it is doubtful if the opportunities there are so good as in America.

For the Tertiary faunas of the Caribbean region, it is important to know what the age of the faunas is in terms of the European time-scale, as an end in itself; but there are other reasons.

One of the important problems confronting geologists at the present time is the more accurate correlation of the Tertiary formations in the Pacific region. That there has been no marine connection between the Mediterranean of Europe with the Indian and Pacific oceans by way of

Tethys since Middle Eocene time is advocated by Martin,[24] the leading authority on the marine invertebrate paleontology of the East Indies. That there was connection between the Atlantic and Pacific oceans across Central America during later Eocene, most of Oligocene, and old Miocene time is well established. The problem of the correlation of the post-Cretaceous formations of the Pacific region has been discussed in two recent symposia. The first was in Honolulu in 1920,[25] and the second[26] was in Melbourne, Australia, in August, 1923. There are several methods by which the problem of correlating the post-Cretaceous formations of the Pacific region may be attacked, and most of these are considered in the two symposia mentioned. One of the methods is by tracing the marine geological formations of Miocene and older age across Central America from the Atlantic to the Pacific and extending the correlations both northward and southward along the Atlantic and Pacific slopes of America. On the west side of the Pacific comparisons may be made with the fossil marine faunas on the east side.

If Nature has placed the base for correlating the post-Cretaceous marine faunas of the Pacific region in tropical America, it is obvious that the completeness of the knowledge of the fossil marine faunas of tropical America and the accuracy of their correlation with European faunas will condition the accuracy of deductions regarding the age of the fossil marine faunas of other parts of the Pacific. Therefore, in solving problems of Tertiary correlation, tropical America is one of the key regions of the world, and in order to advance in the general correlation of Tertiary formations the correlation of the Tertiary formations of eastern America with those of Europe is of vital importance.

It should also be mentioned that knowledge of how the geographic distribution of many marine organisms was brought about is dependent on more precise knowledge of the Tertiary faunas of tropical America. The similarity of a considerable part of the Eocene, Oligocene, and Miocene marine invertebrates of the West Indies and Central America with the living Indo-Pacific faunas has been recognized by many investigators and has already been mentioned in this address. The presence of numerous fossil organisms in both the Atlantic and Pacific basins can apparently be explained only by migration across Central America from one oceanic basin to the other. Two foraminiferal genera to which this ap-

[24] K. Martin: Wann löste sich das Gebiet des Indischen Archipels von der Tethys. Samml. geol. Reichs-Mus. Leiden, ser. 1, vol. 9, 1914, pp. 337-355.

[25] The discussions are published in the Proceedings of the First Pan-Pacific Scientific Conference. Bernice P. Bishop Museum, Specl. Publ., vol. 3, 1921, pp. 713-873.

[26] The discussions are to be published in the Proceedings of the Second Pan-Pacific Science Congress.

plies are *Lepidocyclina* and *Miogypsina*. Where did they originate? From present indications it seems that *Lepidocyclina* originated in America and later migrated eastward to Europe and westward to the eastern Asiatic littoral. The same may be true of *Miogypsina*, because in America it appears to be much older than the European Langhian. Other examples might be given, but these are sufficient to illustrate the point I wish to make.

Another value to be derived from accurate knowledge of the paleontology and geologic correlation of the Tertiary formations of tropical America is a measure of the rate of divergence of the present Atlantic and Pacific faunas from the same fauna and the determination of the effect of different environments on the rate of evolution and the extinction of certain faunal elements. In fact, notwithstanding meager knowledge, enough is now known to form the basis of an essay of moderate length. Ultimately it may be found that climatic oscillation during Miocene time more profoundly affected the marine organisms in the Atlantic than it did in the Pacific, which is a body of water of much greater expanse and volume than the Atlantic, and therefore ecologically a more stable area.

Since it seems probable that the United States Geological Survey and the interested State geological surveys will continue to support studies of the stratigraphy and paleontology of the Coastal Plain, the progress of investigations in that region need not be a matter of concern at present, except that the prompt publication of memoirs on the stratigraphy and paleontology of the Coastal Plain prepared for the United States Geological Survey should be urged and more attention should be paid to micro-organisms. The data contained in the manuscript reports mentioned are needed, both for purely scientific and for economic purposes.

The outlook for the continuance of the investigations in the Caribbean region are not so hopeful as for the Coastal Plain region. It has already been said that the prosecution of studies of the stratigraphy and paleontology of the Caribbean region is important because of the value of the knowledge in solving problems of local and regional correlation, in supplying a basis for the correlation of the Tertiary geologic formations in the Pacific region, in explaining the present geographic distribution of marine organisms, and in getting a measure of the relative rate of organic change in the Atlantic and Pacific basins. These reasons may be considered purely scientific, but results of the investigations indicated are also needed by economic geologists for the assistance they would render in deciphering stratigraphy, especially in areas in which examinations for possible petroleum resources are being made. The first thing

that should be done is to complete studies of the large paleontologic collections already assembled and now in the United States National Museum, especially the fossil mollusks from Costa Rica, Panama, Colombia, Venezuela, and the Dominican and Haitian republics, and to publish the results of the paleontologic studies and the data already available on the stratigraphy of the areas in which the fossils were obtained.

Standard Subdivisions of the European Tertiary Formations

General statement

Because geology as a science was developed in Europe earlier than in other parts of the earth, the standards of geologic chronology were first established there, and, although better localities might have been found elsewhere, it is virtually necessary to try to date geologic events in other parts of the world by reference to that standard.

Major subdivisions of the European Tertiary formations

General statement.—The standardization of the chronology of Tertiary time began with Lyell,[27] who proposed the term Eocene for deposits that contain 3.5 per cent of Recent species of mollusks; Miocene with 17 per cent; and Older Pliocene with 30 to 50 per cent of still living species. Lyell had the cooperation of Deshayes in making the paleontologic definitions. Subsequent to Lyell, Beyrich proposed the term Oligocene[28] for deposits that contain 10 to 15 per cent of living species of mollusks, and Schimper proposed "Paleocene"[29] for old Tertiary plant-bearing deposits. The marine equivalents of the "Paleocene" have in them practically no species that still live. The major divisions of Tertiary time were based on the degree of similarity to and, conversely, degree of difference from the modern molluscan faunas of the North Atlantic Ocean.

D'Orbigny[30] did not like Lyell's classification and therefore proposed the following:

Subappenin.
Falunian..... { upper or Falunian. / lower or Tongrian.
Parisian.
Suessonian or Nummulitic.

There has been much discussion of the most desirable method of subdividing the Tertiary formations and the names that should be applied

[27] Charles Lyell: Principles of Geology, 1833, pp. 45-61.
[28] Beyrich: Stellung der hessischen Tertiärbildungen. Berl. Akad. Wissensch. Monatsber. for 1854, pp. 640-666, 1855. Name proposed, p. 664.
[29] W. Ph. Schimper: Paléontol. végét., vol. 3, 1874, pp. 680-684.
[30] A. D'Orbigny: Cours élém. Paléontol., vol. 2, 1852, p. 704.

to the major subdivisions, but the entire subject can not be reviewed here.[31] Two of the suggestions, however, will be mentioned—those of Renevier and Haug.

Renevier[32] suggested the following classification and nomenclature for the larger subdivisions of the Tertiary:

Recent Neogenic....	Holocene. Plistocene [Renevier's spelling]. Pliocene.
Ancient Neogenic...	Prepliocene. Miocene.
Nummulitic.....	Oligocene. Eocene. Paleocene.

Haug[33] divides the Tertiary into Nummulitic and Neogene, and he subdivides the Nummulitic into Eonummulitic, Mesonummulitic, and Neonummulitic. There is no apparent advantage to be derived from the adoption of Haug's suggestion, especially from an American standpoint. *Nummulites* are not important in American formations, and therefore Nummulitic does not recommend itself for extended use, either on biologic or geographic grounds. Furthermore, the name had been used in a different sense prior to Haug.

Objections will probably be raised to any classification and nomenclature of Tertiary deposits and the corresponding time equivalents. On the whole, the subdivisions Eocene, Oligocene, Miocene, and Pliocene have proved satisfactory and usable.

In order to apply the terms Eocene, Oligocene, Miocene, and Pliocene, the definitions need to be based on type localities and not on merely abstract relations which are supposed to indicate the percentages of species still living. The types of these four divisions of the Tertiary will, therefore, be briefly discussed.

Eocene.—This name was proposed, as already stated, by Lyell. It is easy to find out what Lyell considered type Eocene. Lyell says:[34]

"To this era [Eocene] the formations first called Tertiary, of the Paris and London basins, are referable. Their position is shown in the diagrams Nos. 3 and 4, letter *d*, in the second chapter."

[31] For an excellent history of the earlier endeavors to subdivide, name, and classify the European Tertiary formations, see K. Mayer, Versuch einer neuen Klassification der Tertiär-Gebilde Europa's: Schweizer. Gesellsch. gesam. Naturwiss. Versamml. in Troges, 1857, pp. 165-199, with a correlation table, 1858.

[32] E. Renevier: Chronographe géologique. Congrès géog. internat., Compte-rend., 1897, pp. 521-695, 12 tables.

[33] E. Haug: Traité de géolog., 1911, p. 1397 et seq.

[34] Principles of Geology (1st ed., 1833), p. 55.

It is obvious that Lyell considered the Calcaire grossier of the Paris basin and the London clay of the London basin as particularly characteristic of the Eocene.[35] Lyell also included in the Eocene the "argile plastique" of the Paris basin, which is considered the stratigraphic equivalent of the upper part of the Suessonian. Lyell's Eocene definitely included two stages—the Lutetian and Ypresian of modern usage. It seems logical to extend the application of the term Eocene both downward and upward until some break in the general stratigraphic or paleontologic features is encountered. Downward extension would take in the lower Suessonian or Sparnacian, the Thanetian, and the Montian, while upward extension would include the Bartonian and the Ludian.

Oligocene.—This name was proposed by Beyrich[36] for deposits that are intermediate in age between Lyell's Eocene and Miocene and which were supposed to contain between 10 and 15 per cent of living species of mollusks. Beyrich used the name for deposits in Belgium (Tongrien and Rupelian of Dumont), north and central Germany, and the Mainz basin, but he described in greatest detail and apparently considered as type Oligocene the yellow marine sand in the vicinity of Cassel.

Miocene.—Lyell mentions as typical localities of the Miocene "the Faluns of the Loire" in Touraine, the environs of Bordeaux and Dax, the hills of Mount Ferrat and the Superga Hill near Turin, and the Vienna basin.[37] Although Lyell enumerated several localities, no confusion has resulted, because concurrence of opinion today favors classifying the deposits virtually as Lyell did. In the vicinity of Bordeaux and Dax, Lyell described three formations—an upper or Miocene formation which overlies fresh-water beds, which in turn overlie Eocene limestone. In the lists prepared by Deshayes[38] for Lyell, the localities from the Miocene are Bordeaux and Dax combined as one, Touraine, Turin, and Vienna. With reference to the "Faluns de la Touraine," Lyell's "Faluns of the Loire," they are the type locality of d'Orbigny's restricted Falunian,[39] which he proposed as a substitute for Lyell's Miocene. D'Orbigny unfortunately used Falunian in two senses: In one it comprises what is now considered Oligocene and Miocene; in the other it is equivalent to Miocene of present usage.

It seems that the "Faluns of Touraine" are *par excellence* type Miocene.

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[35] Op. cit.; see also 241-256 and pp. 277-280.

[36] Stellung der hessischen Tertiärbildungen. Berl. Akad. Wissensch. Monatsber für 1854, pp. 640-666, 1855. Name proposed, p. 664.

[37] Lyell: Op. cit., pp. 202-213.

[38] C. Lyell: Principles of Geology, Appendix, 52 pp., 1833.

[39] Cours élément. Paléont., vol. 2, 1852, pp. 775-776.

Pliocene.—Lyell first recognized an Older and a Newer Pliocene,[40] but later he restricted the term Pliocene to his Older Pliocene and named his Newer Pliocene Pleistocene.[41] In the present connection, therefore, only the "Older Pliocene" of Lyell's original classification needs to be considered. To it "belong the formations of Tuscany and of the Subapennine Hills in the north of Italy, as also the English crag."[42] The type area of the Pliocene is the Subapennine Hills.[43] The classification of the Crag of Norfolk and Suffolk is correct. D'Orbigny proposed to substitute "Subapennine" for "Older Pliocene" (later merely Pliocene),[44] but there is no apparent advantage in the change. Lyell pointed out the presence of beds both older and younger than his "Older" Pliocene in the Subapennines, and thereby should have made clear what he meant to include under the term.

The boundaries between the different major divisions of the Tertiary in Europe are not firmly drawn everywhere. There has been dispute as to where the division between Oligocene and Eocene is, and there has been difference of opinion as to whether the Aquitanian should be classified as Oligocene or Miocene. Either one of two conditions are possible: either there may be lack of agreement as to the proper basis for distinguishing between Oligocene and Miocene or information may not yet be adequate for making a definite distinction. However, it seems to me that the divisions in general are satisfactory.

Although it is hoped that the present classification of the Tertiary formations may be improved, I do not share the opinion of Chamberlin and Salisbury[45] that the classification is unnatural. The classification is primarily stratigraphic and biologic, and it is my belief that the principles underlying the attempts at classification are fundamentally correct, notwithstanding the difficulties. Professor Chamberlin advocates diastrophism as the fundamental basis of classification, and both locally and regionally diastrophism is important as a basis for classification, but it can not be made of world-wide application. We have not been able to trace any effects of the Tertiary diastrophism of the Pacific coast of the United States on the Tertiary formations of the Atlantic and Gulf Coastal Plain. Diastrophism is local and regional, not world-wide.

[40] Op. cit., 1833, pp. 53-54.

[41] C. Lyell: Eléments de géologie, 1839, Appendix, pp. 616-621. Paris. On the relative ages of the Tertiary deposits commonly called "Crag" in the counties of Norfolk and Suffolk. Mag. Nat. Hist. (Charlesworth), New Ser., vol. 3, 1839, pp. 313-330 (see p. 323).

[42] C. Lyell: Principles of Geology, 1833, p. 54.

[43] C. Lyell: Op. cit., pp. 155-158.

[44] A. d'Orbigny: Cours élément. paléont., vol. 2, 1852, p. 800.

[45] Text-book of Geology, vol. 3, 1906, p. 191.

Earth strains affect acutely only parts of the earth, and diastrophic adjustments are locally or regionally limited. I therefore believe that diastrophism can not be made the basis of a better classification of Tertiary formation.

STAGE NAMES OF THE TERTIARY FORMATIONS IN EUROPE

No attempt is made to list all the stage names applied to subdivisions of the European Tertiary formations. Only those names that seem to be the most important for correlation purposes are discussed. For these the reference to the first publication and the type locality are given and some comments are added. For the benefit of those who may wish to go into the subject more thoroughly, a list of some of the more important publications are given in the footnote below.[45]

I have not been able to consult the publications in which several of the names first appeared in print. The first edition of Dewalque's "Prodrome

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[45] G. F. Dollfus: Essai sur l'extension des terrains tertiaires dans le bassin Anglo-parisien. Soc. géol. Normandie, vol. 6, 1880, pp. 584-605.

G. F. Dollfus: Classification du tertiaire moyen et supérieur de la Belgique. Soc. géol. France Bull., 4th ser., vol. 3, 1903, pp. 256-260.

G. F. Dollfus: On the classification of the beds of the Paris basin. Geol. Association, London, vol. 21, 1909, pp. 101-118, pl. 5.

G. F. Dollfus: Résumé sur les terrains tertiaires de l'Allemagne occidentale le bassin de Mayence. Soc. géol. France Bull., 4th ser., vol. 10, 1910, pp. 582-625, pls. 8, 9.

Karl Mayer: Versuch einer neuen Klassification der Tertiär-Gebilde Europa's. Schweiz. Gesellsch. gesammt. Naturwiss. Abhandl., 1857 [for meeting in Trogen], pp. 163-199, with one correlation table, 1858. This work gives a rather detailed history of the nomenclature of the stages of the Tertiary formation up to 1857.

Karl Mayer: Classification méthodique des terrains de sédiments, 1874, pp. 23, 4to. Zurich, Librairie Schabelitz (César Schmidt).

Charles Mayer Eymar: Classification des terrains tertiaires conforme à l'équivalence des périhélies et des étages, 1884, pp. 4, 4to. [Appears to have been privately published.]

Charles Mayer Eymar: Classification et terminologie internationales des étages naturels des terrains de sédiment, 1884, 8 pp. Publication apparently as a photolithograph and privately published.

Charles Mayer Eymar: Tableau des terrains de sédiment. Soc. histor.-natur. Croatica Bull., 4th year (iv godina), 1889, pp. 14-47.

Charles Mayer Eymar: Le ligurien et le tongrien en Égypte. Soc. géol. France Bull., 3d ser., vol. 21, 1893, pp. 7-43.

Munier-Chalmas and A. de Lapparent: Note sur la nomenclature des terrains sédimentaires. Soc. géol. France Bull., 3d ser., vol. 21, 1894, pp. 438-488, 3 tables.

E. Renevier: Tableau des terrains sédimentaires formés pendant les époques de phase organique du globe terrestre, avec leurs représentants en Suisse et dans les régions classiques, leurs synonymies et les principaux fossiles de chaque étage. Soc. vaudoise Sci. nat., vol. 13, pp. 218-253, 9 tables; tables 1-3, 1873; tables 4-9 and text, 1874.

E. Renevier: Chronographie géologique—Texte explicatif suivi d'un répertoire stratigraphique polyglotte. Congrès géol. internat., 6e session. Compte-rendu, 1897, pp. 521-695, 12 large tables in color. [This is a second edition of the former work.]

F. Sacco: Classification des terrains tertiaires, conforme à leurs facies. Soc. belge de Géol. et de Paléont. Bull., vol. 1, 1888, pp. 276-294, pl. 11.

F. Sacco: Sur la classification des terrains tertiaires. Congrès géol. internat., 6e session. Compte-rendu, 1897, pp. 309-320, 1 table.

Besides these publications see the text-books of Prestwich, Geikie, Keyser, de Lapparent, and Haug.

d'une description géologique de la Belgique" (1868), de Rouville's "Description géologique des environs de Montpellier" (1853), and Barbot de Marny's "Esquisse géologique du Gouvernement de Cherson" (1869) seem not to be in Washington.

Any general treatment of the European stage name for Tertiary deposits must be expressed in terms of regional correlation. The accompanying table, which is slightly corrected, was compiled by Doctor Julia Gardner and published in the paper by me cited below.[47] It seems to represent the opinion of the principal European students of the subject.

It occurred to me to give a list of the principal literature on the different Tertiary areas of Europe, but since, except for more recent publications, there are adequate lists in the standard treatises, such as the one Haug published, I will mention in the footnote[48] below only some of the later publications and make a few notes on them.

LIST OF STAGE NAMES OF EUROPEAN TERTIARY FORMATIONS

In the following list the names in black-faced type are here adopted as general stage names.

Eocene

Montian.—Dewalque: Prodrome de description géologique de la Belgique, 1868, page 185; ibid. (reprint), 1880, page 209.

From Mons, Belgium, where it was discovered in wells and borings in and around the city. The deposit is rich in marine fossils, of which some hundreds of species have been described by Cornet and Briart and Cossmann. Haug[49]

[47] T. W. Vaughan: Correlation of the Tertiary formations of Central America and the West Indies. First Pan-Pacif. Scientif. Conference Proc. Bernice P. Bishop, Mus. Spec. Pub., pt. 3, 1921, opposite p. 820.

[48] Jean Boussac: Études stratigraphiques sur le Nummulitique alpin. Carte géol. détaill. France Mém., pp. ix + 662, 10 pls. (heliogr.), 10 maps, 1912. A bibliography at the end of each chapter except the first and last.

Giotto Dainelli: L'Eocene friulana, Monographia geologica e paleontologica. 721 pp., 55 pls., 1 map. Memorie geografiche, Tip. M. Ricci, Firenze, 1915. Bibliography, pp. 145-157.

Ramiro Fabiani: Il paleogene del Veneto. R. Univ. Padova Ist. geol. Mem., vol. 3, 1915, pp. 1-336, 9 pls. Bibliography.

Ramiro Fabiani: Il terziario del Trentino. Ibid., vol. 6, 1922, pp. 1-60. Bibliography, pp. 6-8 (45 titles).

Paul Lemoine: Géologie du Bassin de Paris. Pp. ii + 408, 9 pls., 137 text figs. Hermann and Fils, Paris, 1911. Bibliography, pp. 349-377.

Maurice Leriche: Les terrains tertiaires de la Belgique. Congrès géol. internat., 13e sess., Livret guide, pp. 46, 1 map, 1922. Bibliography, pp. 44-46. A fuller bibliography by the same author in Soc. géol. France Bull., 4th ser., vol. 12, 1915, pp. 686-689.

Paul Oppenheim: Die Priabonaschichten und ihre Fauna. Palæontographica, vol. 47, 1901, pp. 1-348, pls. 1-21. Although this is not a recent work, having been published 22 years ago, it is one of the most important publications on the north Italian Tertiary formations and needs to be taken in connection with the studies by Dainelli, Fabiani, Sacco, and Stefanini.

Frederico Sacco: Les étages et les faunes du Bassin tertiaire du Piémont. Soc. géol. France Bull., 4th ser., vol. 5, 1905, pp. 893-916.

Giuseppi Stefanini: Il Neogene del Veneto. R. Univ. Padova Ist. geol. Mem., vol. 3, 1915, pp. 337-624, pls. 10-17.

[49] E. Haug: Traité de géol., 1911, p. 1406.

		ENGLAND
PLEISTOCENE	SICILIAN (ARNIAN)	Icenian { Weybourne *Tellina bal* Chillesford rine) Norwich Cra *borealis*
PLIOCENE	ASTIAN	Butleyan—Butley Re *Cardium groenlandica* Newbournian—Newbo Waltonian { Beaumont Red Cra Walton o Crag
	PLAISANCIAN	Boytonian, Gedgravian } Corallin Lenhamian—Lenham *Arca diluvii*
MIOCENE	PONTIAN	
	SARMATIAN	
	TORTONIAN	
	HELVETIAN	
	LANGHIAN—UPPER	
	LANGHIAN—LOWER	
	AQUITANIAN	
OLIGOCENE	CHATTIAN	
	RUPELIAN	Hempstead beds
	SANNOISIAN	Bembridge and Osborne Headon beds—Upper a
EOCENE	LUDIAN	Headon beds—Lower
	BARTONIAN	Barton Clay Bagshot beds—Upper
	AUVERSIAN	
	LUTETIAN	Bracklesham beds Bagshot Sands—Lower
	YPRESIAN	London Clay
	SPARNACIAN	Oldhaven beds Woolrich and Reading b
	THANETIAN	Thanet Sands
	MONTIAN	

[1] Pliocene adapted from Harmer, F. W.,
Eocene and Oligocene adapted from Ge
[2] Kayser, Emanuel, Lehrbuch der Geolog
[3] de Lapparent, A., Traite de Geologie:
[4] Haug, Emile, Traite de Geologie, vol. 2
[5] Mordziol, Carl, Untersuchungen uber di
Verhand. Jahrg.67, pp. 237–267.

England [1]	Low Countries	North Germany and Denmark	Mainz Basin
Weybourne Crag with *Tellina balthica* Chillesford beds (estuarine) Norwich Crag with *Astarte borealis*			Fresh water and lignitic clays a sands [2]
an—Butley Red Crag with *ium groenlandicum* urnian—Newbourn Red Crag Beaumont and Oakley Red Crag Walton or Naze Red Crag	Amstelian [2] Poederlian with *Corbula gibba* [2] Scaldisian with *Fusus contrarius* [2]		*Prosothenia* marls of Praunhei
Coralline Crag	Casterlian with *Isocardia cor* [2]		
nian—Lenham beds with *diluvii*	Diestian [2]		
	Anversian with *Panope menardi* [2]	Schleswig-Holstein mica clays [4]	*Hydrobia slavonica* clays [2] *Dinotherium giganteum* sands [4] Oeningen flora of Switzerland [2]
			Melania escheri sands [2] *Helix sylvana* beds [2] Steinheim beds of South German
		Holstein beds [2] Lignite and basalt of Hesse [2]	
	Bolderian [2]		
		Brothener Ufer sandstone [2]	*Hydrobia ventrosa* beds [5]
			Hydrobia inflata beds [5]
			Corbicula beds [5]
		Sternberger beds [2 10]	*Cerithium* beds [5]
	Chattian (absent in Flanders) [4]	Kassel sands [2]	*Cyrene* beds [2]
ead beds	Rupelian Clay [2] Rupelian Sand [2] Tongrian—Upper (Henis beds) [2]	Rupelian or Septaria Clay [2] In part Stettiner Sand [2] contempo- Magdeburg Sand [2] raneous	Rupelian—Upper [2] Rupelian—Middle [2] Reiter beds Rupelian—Lower [2] Alzeyer marine sands [2]
dge and Osborne beds beds—Upper and Middle	Tongrian—Lower [2]	Egeln-Lattorf Clay [2] Samland glauconitic sands [2]	
beds—Lower	Asschian [4]		
Clay beds—Upper	Wemmelian with *Nummulites variolarius* [2]		
	Ledian [2]	Eocene recognized in well borings in Denmark, Schleswig Holstein, Mecklenburg, Pommerania, etc.[2]	
sham beds Sands—Lower	Laekenian [2] Bruxellian with *Venericardia planicosta*[2]		
Clay	Paniselian [2] Ypresian with *Nummulites planulatus* [2]	Clays and basaltic tuffs [2]	
n beds n and Reading beds	Lendinian—Upper [2]	Paleocene known in Germany only from well borings [2]	
Sands	Lendinian—Lower (Heersian) [2]	Kerteminde marls of Seeland, Finland, and Jutland [2] Glauconitic marls of Lellinge [2]	
	Mons limestone [2]	Glauconitic, lignitic clays of Copenhagen [2]	

Harmer, F. W., Pliocene Mollusca of Great Britain: vol. 2, pt. 1, pp. 485–652; plates 45–52. Paleontograph Soc., London, 1920.
dapted from Geike, Sir Archibald, Text Book of Geology: 3rd ed., 1147 pp., 471 figs. London, 1893.
rbuch der Geologischen Formationskunde, 852 pp., 190 figs., 97 plates. Stuttgart, 1913.
e de Geologie: 2014 pp., 883 figs. Paris, 1906.
Geologie, vol. 2, pp. 1397–2021. Paris, 1907.
chungen uber die Lage der Oligocan-Miocan Grenze im Mainze Becken: Naturhist. Vereins Preuss. Rhinelande u. Westfalens, pp. 237–267. Bonn, 1911.

TABLE NO. 1—CORRELATION OF THE TERTIARY FORMATIONS OF EUROPE

ERMANY AND DENMARK	MAINZ BASIN	PARIS BASIN [6]	SOUTHWESTERN FRANCE	
	Fresh water and lignitic clays and sands [3]	Saint Prest sands	Saint Prest sands [8]	Villafranchian [8] Terrestrial and
	Prosothenia marls of Praunheim [3]			Yellow sands of *Tapes senescen*
		Bosq d'Aubigny beds	*Nassa* beds of Redon and Bosq d'Aubigny [8]	Blue marls of *Nassa semisir* Zanclean white Sulfo-gypseous
olstein mica clays [4]	*Hydrobia slavonica* clays [2] *Dinotherium giganteum* sands [4] Oeningen flora of Switzerland [2]	*Cardita striatissima* beds	Redonian—Upper [4]	*Dinotherium* bed
	Melania escheri sands [2] *Helix sylvana* beds [2] Steinheim beds of South Germany [3]	Gourbesville conglomerate		Marls and cong *rubiginosum*, *gigensis* [3]
ls [2] basalt of Hesse [3]		Anjou Molasse	Redonian—Lower [7] Shell marl of Salles [7]	Blue marls of T *diformis* [8]
		Shell marl of Touraine	Savignen [7] Pontilevien [7] Armagnac Molasse with *Ostrea crassissima* [7]	*Cardita* marls *diluvii* [8]
fer sandstone [3]	*Hydrobia ventrosa* beds [4]	Salogne sands	Pont Pourquoy shell marl [7] Coquilliere shell marl [4]	Pteropod marl w Littoral marine
	Hydrobia inflata beds [4] *Corbicula* beds [4]	Orleanais sands and marls	Coquilliere shell marl [4] Peloua shell marl [4] Leognan molasse ossifere [4]	Littoral marine *digalensis* [8]
beds [2] [10]	*Cerithium* beds [4]	Orleanais limestone Gatinais Molasse Beauce limestone	Agenais grey limestone with *Lepidocyclina raulini* and *L. dilatata* [4] Agenais sands and limestones with *Ostrea agenensis* [7]	Limestones, sand conitic, with and *Lepidocycl*
n [2]	*Cyrene* beds [2]	Etampes limestone	Agenais white limestone with *Planorbis* and *Helix ramondi* [4]	*Nummulites vasc* *dilatata* and *L.*
Septaria Clay [2] In part nd [2] contempo- Sand [3] raneous	Rupelian—Upper [2] Rupelian—Middle [2] Reiter beds Rupelian—Lower [2] Alzeyer marine sands [2]	Fontainebleau sands *Ostrea* marl	Biarritz marl with *Perculina complanata* [4]	*Nummulites vasc* *salina* [9]
rf Clay [3] uconitic sands [2]		Brie limestone White and green marls	Barritz sandy marls with *Nummulites* and *Scutella* [4] Lacustrine limestone of Castillon [4] Gypseous sands and lignite beds of Languedoc [3]	*Nummulites inte* *arcuatus* [9]
		Gypseous beds with intercalated marine marls Noisy-le-Sec limestone	Blue clays with *Nummulites fabianii* and *N. bouilleri* [4] Castlemaudary gypseous beds [3]	*Nummulites fa* *brogniarti* [9]
ognized in well borings ark, Schleswig Holstein, urg, Pommerania, etc.[3]		Marines and Cresnes sands St. Ouen limestone Mortefontaine zone	Blaye clays [4] Biarritz marl with *Nummulites fabianii* [4] Biarritz *Pleurotoma* marl [9]	*Nummulites fabi* *rosacea* and *Ce*
		Ducy limestone Sands of Ezanville, Beauchamp, Ermenonville, Guepelle, Auvers and Mont St. Martin	Biarritz blue marl with *Nummulites variolarius* and *N. aturicus* [4]	*Nummulites brog*
		Nummulites laevigatus beds. Miliola limestone. *Cerithium lapidum* beds. *Cerithium giganteum* beds. *Ditrupa strangulata* beds. Chaumont-en-Vexin sands	Biarritz white and yellow limestone with echinoderms [4] Calcaire grossier of Blaye [4] *Nummulites atacius* beds with *Orbitolites complanatus* [4]	*Nummulites perf* *Nummulites irreg* *Nummulites laevi*
asaltic tuffs [3]		Laon clay Sands of Herouval, Cuise, Pierrefonds, and Aizy Mont-Notre-Dame tuff and Sinceny and Pourcy beds	*Nummulites planulatus* limestone of Aquitania [9] Royan nummulitic sands [3] *Alveolina oblonga* limestone [3]	*Nummulites bol* *chonella polym*
nown in Germany only borings [2] marls of Seeland, Fin- Jutland [2] marls of Lellinge [2]		Soissons lignite and plastic clay	*Operculina herberti* beds [3]	
		Bracheux sands	*Alveolina* limestone [3]	
lignitic clays of Copen-			Laustrine and fresh water limestone [2]	

plates 45–52. Paleontograph Soc., London, 1920.
71 figs. London, 1893.
art, 1913.

hist. Vereins Preuss. Rhinelande u. Westfalens,

[6] Lemoine, Paul, Geologie du Bassin de Paris: 377 pp., 136 figs., 9 plates. Paris, 1911.
[7] Cossman & Peyrot, A., Conchologie Neogenique de l'Aquitaine: Soc. Linn. de Bordeaux, Actes, vol. 63, pt. 1
[8] Stefanini, Giuseppe, Il Neogene Veneto: Monografia sui Terreni Terziari del Veneto, Padova, R. Universita, 1
plates 10–17. 34 text figs. 1915.
[9] Fabiani, Ramiro, Il Paleogene Veneto: Monografia sui Terreni Terziari del Veneto: Padova, R. Universita,
1–9; 36 text figs. 1915.
[10] Casselian and Aquitanian not separated by Kayser.

Italy		
Villafranchian [1] Terrestrial and fluviatile deposits [1]	Sicilian (Arnian)	Pleistocene
Yellow sands of the Venetian basin with *Tapes senescens* [1]	Astian	Pliocene
Blue marls of the Venetian basin with *Nassa semistriata* and *Pecten cristatus* [1]	Plaisancian	
Zanclean white limestone of Sicily [2] Sulfo-gypseous beds of Sicily [2]		
Dinotherium beds with *Melania escheri* [1]	Pontian	Miocene
Marls and conglomerates with *Cerithium rubiginosum*, *C. pictum* and *Ostrea gigensis* [1]	Sarmatian	
Blue marls of Tortona with *Ancilla glandiformis* [1]	Tortonian	
Cardita marls and sands with *Arca diluvii* [1]	Helvetian	
Pteropod marl with *Aturia aturi* [1] Littoral marine deposits [1]	Langhian—upper	
Littoral marine deposits with *Pecten burdigalensis* [1]	Langhian—lower	
Limestones, sands, and marls, often glauconitic, with *Scutella subrotundiformis* and *Lepidocyclina elephantina* [1]	Aquitanian	
Nummulites vasca zone with *Lepidocyclina dilatata* and *L. marginata* [1]	Chattian	Oligocene
Nummulites vasca zone with *Nattica crassatina* [1]	Rupelian	
Nummulites intermedia zone with *Pecten arcuatus* [1]	Sannoisian	
Nummulites fabianii with *Gryphaea brogniarti* [1]	Ludian	Eocene
Nummulites fabianii zone with *Sismondia rosacea* and *Cerithium diaboli* [1]	Bartonian	
Nummulites brogniarti zone [1]	Auversian	
Nummulites perforata zone [1] *Nummulites irregularis* zone [1] *Nummulites laevigata* zone [1]	Lutetian	
Nummulites bolcensis zone with *Rhynchonella polymorpha* [1]	Ypresian	
	Sparnacian	
	Thanetian	
	Montian	

es, vol. 63, pt. 1, 718 pp., 28 plates. 1909.
R. Universita, 1st. Geol., Mem., vol. 3, pt. 2, pp. 337–624;

, R. Universita, 1st. Geol., vol. 3, pt. 1, pp. 1–336; plates

has given a succinct summary of the features of the formation at its type locality. There has been controversy as to whether the Montian should be classified as Cretaceous or Tertiary. Since a review of this controversy here would require too much space, it will only be remarked that Dewalque seems to be correct in his opinion that the Montian is younger than the Maestrichtian.

Thanetian.—Renevier: Société vaudoise Scientifique naturelle, volume 13, 1873, table 3.

From Isle of Thanet. Two good descriptions of the Thanet sands are referred to in the footnote below.[50] The name Thanet sands was first proposed by Prestwich in 1852.[51] The Thanet sands represent the base of the Eocene in the London basin, where they contain a moderate-size marine fauna. Prestwich considers the Lower Lendinian strata of Dumont in Belgium as the "exact equivalents of the Thanet Sands," and he considers that there is "hardly sufficient reason why the Heersian of Dumont should be separated from the Lower Lendinian." The Heersian strata lie just above the Montian and contain a remarkable flora, "the oldest known European Tertiary flora."

Suessonian.—D'Orbigny: Cours élémentaire Paléontologie, volume 2, 1852, page 712.

From Soisson, on the Aisne. D'Orbigny included both the lignites of Soisson and the overlying sands in his Suessonian. Dollfus in 1880 referred the lignitic horizon to his Sparnacian and the second horizon to his Cuisian = Ypresian of Dumont.

Soissonian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Abhandlungen, 1857; Trogen, 1858, page 173.

From Soisson, Paris basin. The Soissonian of Mayer is the equivalent of the lower part of the Suessonian of d'Orbigny, the Soissonian + Londinian of Mayer being equivalent to d'Orbigny's Suessonian. Although the Sparnacian of Dollfus is a synonym of Soissonian, since Soissonian is substantially the same name as Suessonian, but with a different significance, Sparnacian is the preferable term.

Sparnacian.—Dollfus: Société géologique Normandie, volume 6, 1880, page 588.

From Epernay, on the Marne. Dollfus applies this name to the lower part of d'Orbigny's Suessonian—that is, to the lignitic deposit of Soisson, "which is a vast fluvio-marine formation. The country, low-lying, appears to have been occupied by an enormous river emptying into a shallow sea." The Sparnacian at its type locality has supplied a rich and diversified flora. The "argile plastique" of Paris is considered by Dollfus to be a different sedimentary facies of virtually the same horizon. The Cuise sands belong to an immediately higher horizon.

[50] John Phillips: Manual of Geology, 1885, p. 604.
Joseph Prestwich: Geology—chemical, physical, and stratigraphical, vol. 2, 1888, p. 338.

[51] Geol. Soc. London Quart. Jour., vol. 8, 1852, p. 237.

Ypresian.—Dumont: Académie des Sciences Belge Bulletin, volume 16, part 2, 1849, page 368.

From Ypres. This stage includes the clay of Flanders and sand with *Nummulites planulatus*. The clay contains a rich flora. The Ypresian is considered the correlative of the London clay, and the Cuisian of Dollfus is a synonym.

Cuisian.—Dollfus: Société géologique Normandie, 1880, page 589.

From Cuise-la-Motte. Dollfus divided the Suessonian of d'Orbigny into two stages; the lower he designates the Sparnacian and the upper the Cuisian. The Cuisian is an extensive marine arenaceous deposit in the Paris basin; it grades northward into the Ypresian clays of Flanders and is the stratigraphic equivalent of the London clay. *Nummulites planulatus* is considered a characteristic fossil. Dollfus gives an excellent succinct description of the distribution and variation of the deposits he classifies as Cuisian, but he does not make clear why Cuisian should be preferred to Ypresian or Londinian.

Lutetian.—De Lapparent: Traité de géologie (first edition), 1883, page 989.

From Lutetia, the Latin name for Paris. The type is the "calcaire grossier" of Paris. Lemoine[52] gives a good description of the "calcaire grossier," in which he recognizes two major subdivisions, a lower marine and an upper lacustrine. The wonderfully rich marine fauna has been the subject of study by many paleontologists and is one of the most famous in the world.

Auversian.—Dollfus: Société géologique Normandie, 1880, page 592.

From Auvers (Oise). De Lapparent[53] says regarding the horizon of Auvers, that it "is characterized by rolled, often broken fossils, siliceous pebbles, and numbers of corals, with pieces of limestone perforated by lithophagi. Its principal fossils are *Cerithium trochiforme*, *Turritella sulcifera*, *Ostrea cubitus*, *Nummulites variolarius*, *Dendrophyllia cariosa*, *Lithodendron irregulare*, etc." The Auversian is considered equivalent to the lower Bartonian and it is doubtful if it should be accorded the rank of a stage between the Lutetian and the Bartonian. It seems more logical to let it be absorbed into the Bartonian. Lemoine considers the Auversian as a lower substage of the Bartonian and applies the name Ermenonvillian to it.[54]

Bartonian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Verhandlungen, 1857; Trogen, 1858, page 178.

From Barton, Hampshire. The deposit at Barton is known as the Barton clay and has long been a familiar term in British Tertiary stratigraphy. The lower part of the Bartonian is correlated with the Auversian, and the Wemmelian of Belgium is considered a precise synonym of Bartonian. The Bartonian contains a rich and diversified marine fauna.

[52] P. Lemoine: Géologie du Bassin de Paris, 1911, pp. 227 et seq.
[53] Traité de géol. (1st ed.), 1883, p. 998.
[54] P. Lemoine: Géologie du Bassin de Paris, 1911, pp. 242 et seq.

Ludian.—De Lapparent: Traité de géologie, third edition, 1893, page 1219; Munier-Chalmas and de Lapparent, Société géologique France Bulletin, third series, volume 21, 1894.

From Ludes, on the Marne. The description of the Ludian by Lemoine[35] is excellent. The marine fauna consists of 83 species, concerning which Jean Roussac says that it represents a date at which the Oligocene fauna had not yet invaded northern Europe, with the great transgression of that epoch. Clays and marls intercalated with the different masses of gypsum [of Ludes] contain a mammalian fauna which Depéret considers of clearly Eocene affinities. Above the Ludian are marls which contain an Oligocene (Sannoisian) invertebrate fauna. There is difference of opinion regarding the significance of the vertebrate fossils found intercalated with and above the gypsum beds in comparison with the invertebrate faunas. The vertebrates of the upper beds of gypsum and the overlying marls are considered of Oligocene (Sannoissian) age.

Priabonian.—De Lapparent: Traité de géologie, third edition, 1893, page 1219; Munier-Chalmas and de Lapparent, Société géologique France, third series, volume 21, 1894, page 479.

From Priabona, Italy. This is the southern or Mediterranean equivalent of the Ludian and corresponds to the first movements that initiated the uplift of the Pyrenees. The Priabonian will receive further attention in the discussion of the European and Tertiary corals and larger Foraminifera, as it constitutes one of the tie points between the American and European Tertiary formations.

Oligocene

Tongrian.—Dumont: Académie des Sciences Belge Bulletin, volume 6, part 2; Société géologique France Bulletin, volume 8, 1839; pages 466, 473-479; Ibid., volume 16, part 2, 1849, page 366.

From Tongres, Belgium. As there has been considerable uncertainty regarding the use of this name, a brief history of it will be given. When Dumont first proposed it, in 1839, he said that "the Tongrian system is the most complex [of the five systems then recognized by him as constituting the Belgian Tertiary formation]. The following kinds of rock are distinguishable: First, greenish sand; second, clay and sand; third, yellowish sand; fourth, flint pebbles." Dumont gives lists of fossils from numbers 1 and 2. In 1849 he says:

"The Miocene terrane is divided into the Tongrian, Rupelian, and Bolderian systems, the names of which recall the localities where these systems are remarkable for the fossils they contain.

"The Tongrian system is composed of a marine and a fluvio-marine stage; the marine or lower stage overlies the Bruxellian, Ypresian, Landenian, or Maestrichtian, from Cassel to beyond the eastern frontiers of Belgium; it often begins with a thin but regular bed of gravel with small grains and, when this bed is absent, by medium-grained, more or less glauconitic sands, which immediately succeed it. Ascending in the section, the last-mentioned sands grade into argillaceous sands with very fine grains, *paillétés*, and the stage ends

[35] P. Lemoine: Géologie du Bassin de Paris, 1911, pp. 254-256.

with glauconitic sands, *paillettés*, less fine, less argillaceous, and sometimes fossiliferous, as at Lethem, Grimmersingen, Vliermael, Hoesselt, etc.

"The fluvio-marine or upper stage comprises lower whitish sands, green clay with *Cyrena*, *Melania*, *Paludina*, cerites of Vieux-Jonc, of Henis, etc., and upper sands with *Pectunculus*, cerites, *Melania*, and *Paludina* of Looz and Klein-Spauwen."

The Tongrian is overlain by the Rupelian, which will be considered later. In another paper, cited below, Dumont says:[58]

"In my report on the geologic map of Belgium, read at the meeting of the Royal Academy of Sciences of Belgium, on November 10, 1849, I gave the following table of the classification of our Tertiary terranes: . . . A classification in which my Tongrian system of 1839 is divided into three systems." . . .

In his papers published in 1849 and 1851 Dumont divided his original Tongrian into three parts: he retained the name Tongrian for the lowest division and he called the upper two Rupelian and Bolderian. Did Dumont have a right to redefine Tongrian? According to his first definition, he included in it his subsequent Tongrian, Rupelian, and Bolderian, while in his later definitions he split his first Tongrian into Tongrian, with Rupelian and Bolderian above it. On account of the confusion that results from the use of one term in two distinct senses, Tongrian should not be available for use as Dumont proposed to restrict it. Another name should be used for the Tongrian of Dumont, 1849 and 1851.

The term Tongrian is used in much of the literature on the Tertiary formations of Europe, and there is so great inconsistency in its application that care must be taken to find out what each author means. It is fortunate that there are valid reasons for entirely rejecting the name.

Sannoisian.—De Lapparent: Traité de géologie, third edition, 1893, page 1263; Munier-Chalmas and de Lapparent, Société géologique France Bulletin, third series, volume 21, 1894, page 480.

From Sannois, near Paris. In the second of the citations above, the authors say:

"We define the Sannoisian or lower Tongrian by saying that it includes the brackish water and marine beds which, in the Paris basin, begin with the supragypseous marls with *Spharoma margarum*, *Nystia duchasteli*, *N. plicata*, and are continued in the *Cyrena convexa* beds, the green clays and the equivalent marine beds of the Brie limestone with *Cytherea incrassata* and *Cerithium plicatum*. In a word, the Sannoisian is contained between the last mass of gypsum with *Palæotherium* and the first Stampian beds with *Ostrea longirostris* and *Ostrea cyathula*."

The term Sannoisian is a synonym of Tongrian as redefined by Dumont in 1849 and 1851, and of the Lattorfian of Mayer-Eymar as modified by Haug.

[58] André Dumont: Note sur la position géologique de l'argile rupelienne et sur synchronisme des formations tertiaires de la Belgique, de l'Angleterre et du nord de la France. Acad. roy. Belg. Bull., vol. 18, no. 8, 1851 (reprint 19 pages; original pagination not preserved).

As pointed out elsewhere in his paper, neither Tongrian nor Lattorfian should be used. Decision, therefore, needs to be made betwen Sannoisian and Ligurian. The latter name is discarded for reasons given in the discussion of it, and preference is given to Sannoisian.

Lattorfian (originally Lattorfon).—Mayer-Eymar: Société géologique France Bulletin, third series, volume 21, 1893, page 8.

From Lattorf, a village in the Principality of Anhalt, northern Germany. The name Lattorfian was proposed by Mayer-Eymar to take the place of "the lower Ligurian," which, according to him, is represented in northern Europe by three kinds of deposits: (1) The lower and middle gypsum, with intercalated marls, of the Paris basin, the faunas of which consists of a mixture of Bartonian and Tongrian species of the same basin and are delta deposits of the Loire-et-Seine, which was fed by many warm springs; (2) the delta deposits, alternately marine and fluviatile, of the Isle of Wight; and (3) the marine deposits, more or less glauconitic, of southern England, Belgium, northern Germany, and the northern shore of Lake Aral. Mayer-Eymar proposed the term Henisien (Henisian) for what he considered "upper Ligurian." Concerning this Haug says:

"The upper part of the stage is fluvio-marine. . . . These brackish-water beds, which reappear in the Paris basin, do not exist in northern Germany; they constitute the Henisian of Mayer-Eymar and have been referred sometimes to the Lattorfian, sometimes to the Rupelian."[37]

It is doubtful whether the use of Lattorfian to include all the Oligocene below the Rupelian is really correct, for that seems not to be the intention of the original proposer of the term.

Ligurian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Verhandlungen, 1857; Trogen, 1858, page 182; Mayer-Eymar, Société géologique France Bulletin, third series, volume 21, 1893, page 7 et seq.

From Liguria, northwestern Italy. Mayer does not describe a type occurrence of the Ligurian, but in the table accompanying his article, opposite "Ligurische Stufe" and under "Ober-Italien," is "*Macigno* des ligurischen Apennins (zu *Voltaggio*, Rigoroso, *Roccaforte*, etc.), des Modenischen und von Toscana." From Mayer's publications it seems that he intended the term Ligurian to apply to that part of the Oligocene below the Rupelian. But the matter is not so simple. Sacco says[38] that "the typical Ligurian is not absolutely a horizon above the Bartonian—that is, Upper Eocene or Lower Oligocene, as is generally indicated—but, on the contrary, it corresponds to different stages and to the Middle Eocene especially." Renevier, 1897, indicates that Ligurian is the equivalent of his Tongrian, which is the Tongrian of Dumont, 1849 and 1851.

There is so much doubt about Ligurian that it seems to me that the name should be dropped, and for the Lower Oligocene I favor using Sannoisian of de Lapparent, as stated elsewhere in this paper.

[37] E. Haug: Traité de Géol., 1911, p. 1447.
[38] F. Sacco: Cong. géol. inter., 6th sess., 1897, pp. 315, 316.

Rupelian.—Dumont: Académie des Sciences Belge Bulletin, volume 16, part 2, 1849, page 367.

From Rupel, Belgium. Dumont say:

"The Rupelian system has, in some localities, as its base a thin bed of sandy clay containing *Nucula;* but oftener it begins with more or less argillaceous, yellowish sands. The upper part is composed of very argillaceous sands and schistoid clays, to which I refer the fossiliferous clays of Rupelmonde, Boom, Hasselt, etc."

The Rupelian is the stage next younger than Dumont's Tongrian of 1849 and 1851 and is the stratigraphic equivalent of the Stampian of Rouville, 1853. Since Rupelian has priority over Stampian and there is no doubt as to its type locality or stratigraphic position, it should be adopted as the general stage name. Another objection to Stampian is mentioned in discussing that term.

Stampian.—D'Orbigny: Cours élémentaire géologique paléontologique, volume 2, 1852, page 764; de Rouville, Description géologique des environs de Montpellier, 1853, page 179 (reference from Munier-Chalmas and de Lapparent, 1894).

From Étampés, about 37 kilometers south of Paris, on the river Juine. D'Orbigny included in his "Stampian" deposits now referred to the Sannoisian, the Rupelian, Aquitanian, and later Miocene up to the Bolderian of Dumont. It seems that de Rouville restricted the term to deposits intervening between the Sannoisian and the Aquitanian. Haug says regarding the Stampian,[59] that "it is a synonym of Rupelian, which was proposed four years earlier for deep-water deposits, or at least for deposits of deeper water than the sands of Fontainebleau, the type of the Stampian of Rouville." The term Stampian, in its restricted significance, is adopted by Munier-Chalmas and de Lapparent.[60]

There are two objections to the term "Stampian." The first is that its later application is different from the original application of d'Orbigny: the second is that in its restricted application it is a synonym of the older term, Rupelian. Therefore "Stampian" should be dropped and Rupelian adopted.

Munier-Chalmas and de Lapparent (1894), in discussing the Stampian, say regarding its Mediterranean facies, that to it correspond the limestone with many corals at Castel Gomberto (Vicentia), where the Stampian fauna of the Paris basin is associated with *Natica angusta*, a species which belongs in the southern fauna. This correlation is the one usually adopted and will be further considered in discussing European and American Tertiary corals. The coral fauna of the Castel Gomberto horizon in Italy constitutes one of the tie points between the American and European Oligocene, and thence to the geologic section in the Paris basin.

Chattian.—Fuchs: Königlich-ungarische geologische Anstalt Mittheilungen aus dem Jahrbuch, volume 10, 1894, page 172.

From Chatti, the Latin name for the people who inhabited Hesse. The

[59] E. Haug: Traité de géologie, 1911, p. 1419.
[60] Soc. géol. France Bull., 3d ser., vol. 21, 1894, p. 480.

actual type locality is Cassel. In the paper cited, full title in footnote,[61] Fuchs shows that fossils from near Krapina[62] and Radoboj, previously considered of Aquitanian age, possess only a very remote resemblance to the Aquitanian fauna, and that they really belong to the Oligocene as represented by the sands at Cassel. Fuchs says that the sands of Cassel must be considered the type of the Upper Oligocene,[63] and, on a subsequent page,[64] that the name Aquitanian stage, according to all the rules of priority, can be applied only to the lowest Miocene beds—that is, the horizon of Molt, Loibersdorf, and Korod—but that it can not be used for the *Pectunculus*-sandstone of Hungary, which is pronouncedly Oligocene and completely agrees with the Upper Oligocene sands of Cassel. In order, he says, to avoid future misunderstandings, he proposes for this Upper Oligocene the name Chattian stage.

The term Casselian of Dollfus, 1910, is a precise synonym of Chattian, Fuchs, 1894.

Casselian.—Dollfus: Société géologique France Bulletin, fourth series, volume 10, 1910, page 582[65] et seq.

From Cassel, Hesse. Dollfus says (regarding Fuchs):

"He proposes to take as the type of the Upper Oligocene the Kassel sands parallel to the Doberg beds near Bünde, the Sternberg sandstone, and the Ormoy beds, and to give to this new stage the new name, Chattian—a name based, we believe, on the name of a Germanic people inhabiting the Kassel region, according to Tacitus."

On the next page[66] Dollfus says:

"Therefore our name Kasselian is a complete synonym of Chattian, as for it likewise the stage of the Kassel sands is designated as the type of the Upper Oligocene." . . .

The only possible objection—perhaps a valid one—to Chattian is that it is based on the name of the people who inhabited an area and not on the name of the area; but until it is an established principle that geologic stage names must be solely taken from place names, Chattian, because of its clear priority, should continue in use.

Miocene

Aquitanian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Verhandlungen, 1857; Trogen, 1858, page 188.

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[61] Tertiaerfossilien aus den Kohlenführenden Miocaenablagerungen der Umgebung von Krapina und Radoboj und über die Stellung der sogenannten "Aquitanischen" Stufe Op. sup. cit.

[62] Krapina is in the province of Varazdin, Croatia, about 37 kms. west of north from Agram. I have not found Radoboj on a map.

[63] Op. sup. cit., p. 167.

[64] Op. sup. cit., p. 172.

[65] In a footnote on this page Dollfus refers to previous articles by him, as follows: "B. S. G. F., 7 juin, 1909 (4), IX, p. 286. C. R. som. séances Soc. géol., 2 mai, 1910 (étage Kasselian); 6 juin, 1910 (Environs de Mayence). I did not find the term Kasselian at any of these references, and apparently it was first introduced in print as indicated above.

[66] Op. sup. cit., p. 625.

From Aquitaine, southwestern France. Mayer states in detail the position of the outcrops of the Aquitanian near Bordeaux. Later, Dollfus made a careful restudy of the type locality.[67] The type exposures are in "the Valley of Saint-Jean-d'Étampes (Gironde), between Moulin de Bernachon, on the edge of the town of La Brède, and Moulin de l'Église, situated upstream, in the territory of the Commune of Saucats."[68]

Dollfus also says that "the Aquitanian is a rational stage, perfectly defined, bound together in all its parts, and clearly limited in its type region at its base and at its top; it belongs by its fauna, without hesitation, to the Lower Miocene."[69]

It is not practicable to review here the literature as to whether the Aquitanian is uppermost Oligocene or lowest Miocene, but it will be said that the evidence presented by Dollfus, Fuchs, Oppenheim, and others seems convincing that the typical Aquitanian is Miocene. If the American strata correlated with the European Aquitanian are really of Aquitanian age, they will also have to be referred to the Miocene.

Langhian.—Pareto: Société géologique, second series, volume 22, 1865, page 229.

From Langhe Hills, Piedmont, Italy. Pareto did not clearly define his Langhian, and therefore I examined the works of Sacco[70] and Stefanini[71] for additional information. Sacco does not give any information that will aid in forming an opinion, although he uses the term. Stefanini discusses whether certain strata are referable to the Langhian, and he says that the strata he refers to the Langhian "contain a fauna evidently similar to that of the terranes in the valley of the Rhone and in the basin of Aquitaine which go under the name of Burdigalian—a name, in my opinion, unjustly substituted by Depéret for the older and accredited name of Pareto."

Depéret, because the fossiliferous beds at Superga Hill near Turin do not belong to the base of the Second Mediterranean stage of Suess, abandoned Langhian. He says, however, that immediately below the horizon of the fauna at Superga Hill are the marls of Langhe, which have the facies of the "schlier" and belong to this horizon, as Suess supposed.[72] The "schlier" represents the base of Suess's Second Mediterranean stage and belongs to the Burdigalian of Depéret,[73] who says that the fauna of the "schlier" is analogous to that of the blue marls of Langhe, the type of the Langhian of Mayer.[74] I agree with Stefanini in his opinion that Depéret should not have introduced the term Burdigalian to replace Langhian, but should have used Langhian.

Burdigalian.—Depéret: Société géologique France Bulletin, third series, volume 20, 1892, page clv; ibid., volume 21, 1893, page 263.

[67] A. F. Dollfus: Essai sur l'étage aquitanien. Serv. Carte géol. France, vol. 19, 1909, pp. 379-508, 6 pls.
[68] A. F. Dollfus: Op. sup. cit., p. 380.
[69] Op. sup. cit., p. 379.
[70] F. Sacco: Internat. Geol. Congress, 6th sess., Comptes rend., 1897, pp. 317-318.
[71] G. Stefanini: R. Univ. Padova Ist. Geol. Mem., vol. 3, 1915, pp. 518-521.
[72] C. Depéret: Soc. géol. France, 3d ser., vol. 20, 1892, p. cliv.
[73] C. Depéret: Op. sup. cit., p. cl.
[74] Pareto, not Mayer, is the original proposer of Langhian.

From Burdigalia, Latin name for Bordeaux. Depéret says that "above the usually lagunal formations of the *Aquitainian* there are distinguishable in the marine Miocene a great lower stage with the horizon of the 'faluns' of Saucats and Leognan at its base and that of the 'mollasse calcaire' of the Rhône basin with *Pecten praescabriusculus* at its top. The first of these horizons corresponds to a phase at the beginning, not yet pronounced, of the marine Miocene transgression, which in the Rhône basin reached only la Drôme, while at the upper horizon it penetrated into Dauphine, Savoy, Switzerland, and thence through Bavaria into the extra-alpine basin of Vienne. This first natural group of strata can be designated under the name of *Burdigalian*, on account of the rich fauna of the 'falun' of Bordeaux." The type locality of the Burdigalian, therefore, is Bordeaux, and as there are in the vicinity of Bordeaux, or near there, strata of pre-Aquitanian, Aquitanian, and post-Burdigalian age, the term Burdigalian is intended to apply only to those beds that lie between the Aquitanian below and the so-called Helvetian above. Haug gives a good summary, based on the studies of Dollfus and Fallot, of the succession of beds near Bordeaux.[75] Fallot recognizes three horizons in the Burdigalian. Marine fossils are abundant.

Vindobonian.—Depéret: Société géologique France Bulletin, volume 23, procès verbal, 1895, page xxxiv.

From Vindobona, Latin for Vienna, Austria. Depéret proposed this term as a substitute for the Second Mediterranean stage of Suess, because in some regions it is not possible to distinguish between Helvetian and Tortonian on account of the similarity of facies throughout the entire thickness of the Second Mediterranean stage. Depéret considers Helvetian and Tortonian as substages of his Vindobonian.

Bolderian.—Dumont: Académie des Sciences Belge Bulletin, volume 16, part 2, 1849, pages 368-370; ibid., volume 18, number 8, 1851, pages 15-17 (of a reprint).

From Bolderberg, Belgium. Dumont says in 1849:

"The Bolderian system is divided into two stages: a marine stage, the lower part of which consists of glauconitic sands and the upper part of yellowish sands, in which occur the fossiliferous sands of Bolderberg, and a fluviatile stage composed of sand and lignite, of which traces are found under the Campinian soil."

In his paper of 1851 Dumont indicates doubtful correlation of the marine facies of his Bolderian with the Falun of Touraine. The Bolderian has supplied an important marine mammalian fauna.

Helvetian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Verhandlungen, 1857; Trogen, table at end of volume, 1858.

From Helvetia, the Latin name for Switzerland. In the column headed "Schweizerisch-Deutsche Alpen und Hochebene," Mayer says:

"Meeres-Molasse der Umgegend Bern's (Imi. Belpberg, Münsingen, Hütt-

[75] E. Haug: Traité de géologie, 1911, pp. 1610-1613.

lingen), *Luzern's* (*Rangglock, Reuss-Ufer, Rothsee*, etc.), von *Zug, Rapperschwyl, Herisau, St. Gallen, Stocken, St. Georgen, Hagebuch, Steingrube, Martinsbruck*, etc., von *Staad* bei *Rorschack, Bregenz*, v. *Hohenscissenberg*, etc."

There is no type locality indicated, and if more than one horizon is represented at any of the localities listed the name Helvetian is rendered untenable.

The validity of the term Helvetian has been discussed by Dollfus and Dautzenberg,[76] who reject the term because the Swiss mollasse constitutes a poor type, as it embraces deposits ranging in age from Aquitanian, through Langhian, and on upward. They adopt d'Orbigny's Falunian, the type of which, in d'Orbigny's restricted sense, is the Faluns of Touraine; but d'Orbigny used Falunian as the equivalent of Oligocene + Miocene.

Many pages might be written on Helvetian, but to do so would scarcely serve any useful purpose. The name was not properly founded and it should be abandoned, although I am using it as a stage name in this paper.

Tortonian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Abhandlungen, 1857; Trogen, table at end of volume, 1858.

From Tortona, northwestern Italy. Mayer says in the column for upper Italy: "Blue marl with *Conus canaliculatus* and *Ancillaria glandiformia* of *Tortona*, of *Baccdasco* in the *Piaccntino*, of the *Modcnian*, of *Tuscany*," etc. The type locality of the Tortonian is entirely definite. There is question, however, as to whether it is equivalent to or younger than the so-called Helvetian. Two discussions of the Tortonian by Sacco are referred to in the footnote[77] below.

Anversian.—Cogels and van Ertborn: Tableau des formations géologiques des environs d'Anvers, Mélanges géologiques, 1880, page 8.

From Anvers (English, Antwerp). The first use of this name that I have discovered is as given above. In this table Cogels and van Ertborn place the Anversian between the Rupelian Oligocene below and the Diestian Pliocene above, and he divides it into two zones or horizons—the upper, "Sables à *Pectunculus pilosus*," and the lower, "Sables à *Panopæa menardi*."

Dollfus[78] says that the Anversian is the equivalent of his Redonian of western France and is of late Miocene age. The fauna is near that of Bolderberg, the type locality of the Bolderian, but in its ensemble it appears younger. Dollfus considers the true Diestian to be of Pliocene age, as did Cogels and van Ertborn. The deposit at Antwerp, so rich in Cetacean remains, is part of the Anversian.

Sarmatian.—Barbôt de Marny, Esquisse géologique du gouvernement de Cherson, 1869 (reference from Munier-Chalmas and de Lapparent, 1894).

From Sarmatia, the Danube. The Sarmatian seems not to have a definite type locality. There are numerous discussions of the origin of the term, the

[76] Soc. géol. France Mém. no. 27, 1902, p. 8.

[77] F. Sacco: Soc. Belge de géol. et de paléont. Bull., vol. 1, 1887, p. 285; Congrès géol. internat., 6th sess., 1897, p. 318.

[78] F. G. Dollfus: Classification du tertiaire moyen et supérieur de la Belgique. Soc. géol. France Bull., 4th ser., vol. 3, 1903, p. 258.

features of the deposits, and the biologic characteristics. That of Munier-Chalmas and de Lapparent[79] is good. They say:

"The Sarmatian deposits contain a brackish water molluscan fauna whose affinities are with the lagunal species of the Tortonian. This fauna developed in a sea in general only slightly saline, extending over a great part of eastern Europe: Crimea, Bessarabia, Serbia, Rumania, Transylvania, Slavonia, Croatia, Hungary, the Vienna basin, etc. In a large number of localities the Sarmatian beds are formed almost exclusively of cerites, *Cerithium pictum*, *C. rubiginosum*, *C. disjunctum*, *C. spissa*, *C. nodosoplicatum*, etc.

"The Sarmatian is especially characterized by peculiar mollusks, which, if they do not appear at this epoch for the first in Europe, at least then acquire their maximum development, such as *Mactra podolica*, *Tapes greparea*, *Ervilia podolica*, *Trochus podolicus*, *Donax lucidus*."

The mammalian fauna contains *Mastodon*, *Dinotherium*, *Anchitherium*, *Listriodon*, *Dicrocerus*.

Pontian.—Barbôt de Marny, Esquisse géologique du gouvernement de Cherson, 1869 (reference from Munier-Chalmas and de Lapparent, 1894).

From Pont, southern Russia. There seems to be no specific type locality for the Pontian. Munier-Chalmas and de Lapparent say:[80]

"The Pontian sea, after having covered the former site of the Sarmatian sea, advanced from the east to the west and extended successively over a great part of the Apennines, over the shores of Corsica, penetrated the lower valley of the Rhone, and touched the shores of Spain near Barcelona. This great eastern sea, which was cut off from any communication with oceanic waters, was inhabited by a fauna indicative of water with a low salinity; peculiar kinds of *Cardium*, some of which live today exclusively in the Caspian Sea, are characteristic of the Pontian deposits: *Prosodacna*, *Myocardia*, *Lymnocardium*, *Phyllocardium*, *Monodacna*, *Didacna*, *Arcicardium;* the great development of *Congeria* (*Dreyssensia*) and the presence of *Dreyssensomya* and *Valenciennesia* also needs mention."

Munier-Chalmas and de Lapparent consider the Pontian of Upper Miocene age; but other geologists, Kayser, for instance, consider it to be Lower Pliocene.[81]

Pliocene

Plaisancian.—Mayer: Schweizerische Gesellschaft gesammtlicher Naturwissenschaft Abhandlungen, 1857; Trogen, table at end of volume, 1858.

From Piacentino, northern Italy. Mayer, in the column for upper Italy in his table: Blue marl of *Nizza*, *Savona*, *Castelnuovo d'Asti*, *Chieri* at *Turin*, *Cossato* at *Biella*, *Varese* at *Como*, of *Castel-Arquato*, *Tabiano*, etc., in the *Piacentino*, of the *Modenian*, of *Tuscany*, etc.

Munier-Chalmas and de Lapparent make the following comments:[82]

[79] Soc. géol. France Bull., vol. 21, 1894, p. 484.
[80] Soc. géol. France Bull., vol. 21, 1894, p. 485.
[81] E. Kayser: Lehrb. der Geologie, 5th ed., pt. 2, 1913, p. 662.
[82] Soc. géol. France Bull., 3d ser., vol. 21, 1894, p. 487.

"After eliminating from the original Plaisancian of M. Mayer the upper part, which corresponds to the Astian of M. de Rouville, the marine clays of Plaisance (the subapennine marls) become the type of Plaisancian as it is understood today by most geologists.

"Plaisancian deposits cover a large part of the Apennines and extend along the margin of the western Mediterranean, where they cover, in the region north of the Tyrrhenian Sea, the Pontian deposits with *Congeria simplex*. The Plaisancian strata are chiefly represented in the Mediterranean regions by blue clays containing many corals: *Ceratotrochus*, *Trochocyathus*, *Flabellum*, associated with *Pyrula undata*, *Dentalium sexangulare*, *Turritella tornata*, *Xenophora prisca*, *Murex trunculus*, *Strombus coronatus*, *Clypeaster beaumonti*, *C. laganoides*."

The mammalian fauna contains *Hipparion*, *Mastodon*, *Rhinoceros*, *Palaeoryx*, *Cervus*, *Hyenarctos*.

Astian.—De Rouville: Description géologique des environs de Montpellier, page 185, 1853 (reference from Munier-Chalmas and de Lapparent, 1894).

From Asti, in the Piedmont, Italy. Munier-Chalmas and de Lapparent say:[52]

"The second Pliocene stage, created by M. de Rouville for Asti sands, is especially represented in the Mediterranean region by a sandy facies superposed on the blue clays of the Plaisancian. There are found in it: *Pecten latissimus*, *Claravella bacillum*, *Cardium pectinatum*, *C. hirsutum*, *Nucula placentina*, *Tellina lacunosa*, *Nassa murica*, and *Strombus coronatus*.

"At Monte Mario and other places the upper part of the Astian bears in perfect accordance passage beds between the Astian, properly speaking, and the Sicilian, which already contain *Cyprina islandica* associated with *Claravella bacillum*, *Cardium hirsutum*, *Nassa murica*, etc."

The upper part of the Asti sands contain the remains of *Mastodon*, *Elephas*, *Rhinoceros*, *Hippopotamus*, Bos, etc.

Pleistocene

Sicilian.—Doderlein: Note illustrative della carta geologica del Modenese e del Reggiano, page 14 (in footnote), 1872.

From Sicily. The type locality is at Palermo and the type material is a shell-bearing limestone. Doderlein divides the Italian Pliocene into: 1. Una zona recentissima Pleistocenica, o Siciliana; 2. Una zona superiore od Astiana; 3. Una zona medio o Piacentina; 4. Una zona profonda inferiore o Tabianese.[54]

The Sicilian is usually considered of oldest Pleistocene age. Munier-Chalmas and de Lapparent,[55] who refer it to the uppermost Pliocene, say that at this epoch the Pliocene sea attained its maximum regression, and that its general configuration corresponded to the present Mediterranean. Boreal forms of life were abundant and included *Tellina calcaria*, *Mya undevallensis*, *Panopæa norvegica*, *Pecten islandicus*, *Trichotropis borealis*, *Buccinum groenlandicum*, etc.

[52] Soc. géol. France Bull., 3d ser., vol. 21, 1894, p. 488.

[54] This name is taken from Mayer, but, as it is not now in use, its history is not given here.

[55] Soc. géol. France Bull., 3d ser., vol. 21, 1894, p. 488.

Standard Subdivisions of the Tertiary Formations of the Atlantic and Gulf Coastal Plain and of the Caribbean Region

GENERAL STATEMENT

The following account of the standard subdivisions of the Tertiary formations in the regions above indicated is devoted almost entirely to those deposits which may be regarded as standards to be used in the solution of general problems in geologic correlation. Therefore it is not a complete catalogue of stratigraphic terms applied in the region. The selection of terms to be considered had to be made according to some definite set of principles, which are as follows: (1) That the formation should be sufficiently fossiliferous for the deposit to be used as a paleontological standard. In the case of names for nearly the same horizons the more fossiliferous deposits are selected. Therefore, such names as La Cruz and Matanzas marls in Cuba, the Cevicos limestone in the Dominican Republic, and many others are omitted. I have omitted the names applied in Porto Rico because the time intervals represented there are represented elsewhere by paleontologically richer or better known deposits. A few names, such as Mao Adentro limestone and Mao clay, in the Dominican Republic, are included to complete geologic sections, although the deposits to which the names are applied are not of great significance for correlation purposes. (2) That the stratigraphic relations of the deposit named must be known, preferably because of superposition, but in making the selection inference from biologic character is not excluded.

For each unit as much of the following information as is practicable is given: References to the original publication of the name and description of the unit and to important subsequent elaborations; source of the name; the type locality; and notes on stratigraphic relations and contained organisms.

Two correlation tables are introduced here—one for the south Atlantic and eastern Gulf Coastal Plain, the other for the West Indies and Central America. Both tables are modifications of tables previously published by me.[86] Dr. C. W. Cooke and Dr. W. P. Woodring have helped me in bringing the tables up to date (November, 1923). There are on these tables several names which are not explained in the following account of geologic formation names.

[86] T. W. Vaughan: Correlation of the Tertiary formations of Central America and the West Indies. First Pan-Pacific Scientific Conference Proc. Bernice P. Bishop, Mus. Spec. Pub. no. 7, 1921, pp. 820, 826.

A new dictionary of stratigraphic terms for America, particularly the United States, is urgently needed, but much aid may still be obtained for the Tertiary formations from the papers by Harris,[87] Dall,[88] and Weeks,[89] cited below.

EOCENE

General statement.—The Eocene formations will be discussed under two areal subdivisions: The Atlantic and Gulf Coastal Plain and the West Indies.

Atlantic and Gulf Coastal Plain—The subdivisions.—Four major subdivisions are recognized in the Eocene of the Atlantic and Gulf Coastal Plain. These are the Midway, Wilcox, and Claiborne groups and the Jackson formation and its stratigraphic equivalents. Each of the groups is composed of several formations which are discussed on subsequent pages. The Jackson formation is a local name applicable in Mississippi, Alabama, and Louisiana. Where the Jackson time interval is represented by deposits of different facies other names are applied.

Midway group.—G. D. Harris: The Midway stage. American Paleontology Bulletin, volume 1, 1896, page 11.

From Midway Landing, on the west side of Alabama River, about five miles below Prairie Bluff, Wilcox County, Alabama. The name Midway was proposed by E. A. Smith and L. C. Johnson[90] for the lowest division of the Eocene in Alabama, but its scope was enlarged by Harris so as to include three of the original subdivisions of Smith and Johnson—the Clayton limestone, Sucarnochee clay, and Naheola marl. Although the question of the nomenclatorial propriety of changing the scope of the term might be raised, the practice of using Midway in a group sense, as initiated by Harris, has been followed by subsequent students of the Eocene of the Coastal Plain.

Clayton formation.—E. A. Smith, L. C. Johnson, and D. W. Langdon: Report on the geology of the Coastal Plain of Alabama. Alabama Geological Survey, 1894, page 192.

From Clayton, "the county seat of Barbour County, Alabama, where the limestone and other characteristic beds are so well exposed." This is the basal formation of the Midway group and is the lowest Eocene known in the Coastal Plain. It unconformably or disconformably immediately overlies the Upper Cretaceous. The fauna has been comprehensively described by a number of paleontologists, the corals by myself, the Bryozoa by Canu and Bassler, and the mollusks by Aldrich, Harris, and others.

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[87] G. D. Harris: List of names applied to Cenozoic beds and formations of the United States, excluding the Laramie. W. H. Dall and G. D. Harris: Correlation papers, Neocene. U. S. Geol. Survey Bull. 84, 1892, pp. 320-338.

[88] W. H. Dall: A table of the North American Tertiary horizons correlated with one another and with those of western Europe, with annotations. U. S. Geol. Survey 18th Ann. Rept., pt. 2, 1898, pp. 323-348.

[89] F. B. Weeks: North American geologic formation names. Bibliography, synonymy, and distribution. U. S. Geol. Survey Bull. 191, 1902, 448 pp.

[90] U. S. Geol. Survey Bull. 43, 1887, p. 18.

TABL

AGE OF DEPOSITS	EOCENE			OLIGOCENE		MIOCENE			PLIOCENE
	lower	middle	upper	lower	upper	lower	middle	upper	

TABLE 2.—CORRELATION TABLE OF THE TERTIARY FORMATIONS OF THE SOUTH ATLANT

AGE OF DEPOSITS		NORTH CAROLINA (South of Hatteras axis)	SOUTH CAROLINA (Santee drainage)	SOUTH CAROLINA AND GEORGIA (Savannah drainage)	GEORGIA (Chattahoochee drainage)	FLORIDA
PLIOCENE		Waccamaw marl	Waccamaw marl	(Not recognized)		Caloosahatchee marl, Nashua marl, Alachua clay, and Bone Valley gravel (largely contemporaneous)
MIOCENE	upper	Duplin marl Unconformity	Duplin marl —Unconformity—	Duplin marl —Unconformity—		Jacksonville formation
	middle		Edisto marl			
	lower			—Unconformity—		—Unconformity—
				Marks Head marl	Chipola formation	Alum Bluff group: Shoal River for; Oak Grove san; Chipola format
OLIGOCENE	upper				Chattahoochee formation	Tampa formation; Cha form
					—Unconformity—	
	middle				Absent	Byram calcareous
					Gl'on formation	Glendon formati
	lower			Vicksburg formation	—Unconformity— Absent	Vicksburg group: Marianna limest ern Florida)
EOCENE	upper	Castle Hayne limestone	Cooper marl / Barnwell formation	Barnwell formation (with Twiggs clay member)	Ocala limestone	Ocala limestone
	middle		McBean formation	McBean formation	McBean formation	(Buried)
	lower		Congaree shales of Sloan Williamsburg formation	(Probably overlapped)	Wilcox formation	(Buried)
			Black Mingo formation	(Probably overlapped)	Midway formation	(Buried)

NOTE—The United States Geological Survey now classifies the Chattahoochee, Tampa, and most of the Cata marl to the Upper Oligocene. I concur in this decision which reached me too late for incorporation in thi

GEORGIA (Chattahoochee drainage)	FLORIDA		ALABAMA		MISS
	Caloosahatchee marl, Nashua marl, Alachua clay, and Bone Valley gravel (largely contemporaneous)	Citronelle formation	Citronelle formation		Citronelle for
	Jacksonville formation	Choctawhatchee marl	Pascagoula clay		Pascagoula c
	—Unconformity—				
	Alum Bluff group: Shoal River formation			Hattiesburg clay	Hattiesburg
	Alum Bluff group: Oak Grove sand				
formation	Alum Bluff group: Chipola formation		Chipola formation		
hoochee for-	Tampa formation	Chattahoochee formation	Chattahoochee formation	Catahoula sandstone	Catahoula sa
nformity— bsent					
n formation onformity—	Vicksburg group: Byram calcareous marl		Vicksburg group: Byram calcareous marl		Vicksburg group: Byram cal
	Vicksburg group: Glendon formation		Vicksburg group: Glendon formation		Vicksburg group: Glendon li
Absent	Vicksburg group: Marianna limestone (western Florida)		Vicksburg group: Marianna limestone		Vicksburg group: Marianna Mint Spri marl mem
			Vicksburg group: Red Bluff clay		Vicksburg group: Red Bluff
mestone	Ocala limestone		Ocala limestone	Jackson formation	Jackson for Yazoo clay Moodys cal ber)
formation	(Buried)		Claiborne group: Gosport sand		Claiborne group: Yegua for
			Claiborne group: Lisbon formation		Claiborne group: Lisbon for
			Claiborne group: Tallahatta formation		Claiborne group: Tallahatta
rmation	(Buried)		Wilcox group: Hatchetigbee formation Bashi formation Tuscahoma formation Nanafalia formation		Wilcox group: Grenada fo Holly Spri Ackerman
formation	(Buried)		Midway group: Naheola formation Sucarnochee clay		Midway group: Porters Cr Tippah sa ber)
			Midway group: Clayton formation		Midway group: Clayton

s, Tampa, and most of the Catahoula formation as Lower Miocene and refers only the E
too late for incorporation in this table or the text. The reader can easily make the needed

	MISSISSIPPI	LOUISIANA
	Citronelle formation	Citronelle formation
	Pascagoula clay	Pascagoula clay
	Hattiesburg clay	Hattiesburg clay
	Catahoula sandstone	Catahoula sandstone
Vicksburg group	Byram calcareous marl	
Vicksburg group	Glendon limestone	
Vicksburg group	Marianna limestone (with Mint Spring calcareous marl member)	Vicksburg limestone
Vicksburg group	Red Bluff clay	
	Jackson formation (with Yazoo clay member and Moodys calc. marl member)	Jackson formation
Claiborne group	Yegua formation	Claiborne group: Yegua formation
Claiborne group	Lisbon formation	
Claiborne group	Tallahatta formation	Claiborne group: St. Maurice formation
Wilcox group	Grenada formation Holly Springs sand Ackerman formation	Wilcox formation
Midway group	Porters Creek Clay (with Tippah sandstone member)	Midway formation
Midway group	Clayton formation	

refers only the Byram calcareous
y make the needed change.

American Time Subdivisions			Dominican Rep	
			North side	
Pliocene				
Miocene		Upper		
		Middle	Group	Mao clay Mao adentro limestone Gurabo formation (*Scensia laevigata* zone)
		Lower	Yaque	Cercado formation (*Aphera islacolcnis* zone) Baitoa formation and Bulla conglomerate
Oligocene		Upper		Cevicos limestone
		Middle		Tabera [1] formation
		Lower		
Eocene		Upper		Limestone at Damajagua and elsewhere
		Middle		
		Lower		

TABLE 3.—CORRELATION TABLE OF WEST INDIAN AN

Dominican Republic		Republic of Haiti [1]	Porto Rico [2]	Cuba	Jamaica	
th side	South side					
	Las Matas formation	Hinche formation (non-marine) Marine beds near Jacmel		East of Guantanamo Bay	Manchioneal and Kingston formations [3]	
	Cerros de Sal formation					
ntro limestone ormation *laevigata* zone)	Yaque group not yet divided into formations	South edge of Cul-de-Sac Plain	Ponce lime-stone and Quebradillas chalk	La Cruz marl and Matanzas marl	Bowden formation	
ormation *placolcnis* zone) ormation and onglomerate		Las Cahobas formation. Thomonde formation and Maissade tongue. Madame Joie formation			Near May Pen [4]	
limestone	East of Bani and elsewhere	Limestone around borders of the Central Plain and elsewhere	Aguadilla limestone Lares limestone	Near Pinar del Rio, San Martin and other places	White Limestone: Limestone in Trelawny and elsewhere [5]	
formation	Near Tubano	Limestone in Montagnes Noires, Chaîne des Mateux and elsewhere	Collazo shale and Guanica shaly limestone [6] (= Pepino formation)	East of Guantanamo, near Matanzas, and other places	White Limestone: Limestone in Trelawny and elsewhere [6]	
		?Limestone near Dondon and in the Chaîne des Mateux			White Limestone: Probably present	
t Damajagua sewhere	Limestone in Sierra de Neiba, Sierra de Bahoruco and elsewhere	Limestone in all the mountain ranges		Near Matanzas; Santa Lucia; Ponupo mine; many places in Cuba	White Limestone: Limestone in Trelawny and elsewhere [6]	
		Plaisance limestone			Yellow limestone [7] (including Cambridge formation)	Near Texas border

[1] Lower part of this formation may be of lower Oligocene age.
[2] After Woodring, Brown, and Burbank, Geol. Repub. Haiti (1924).
[3] Adapted from Maury (1920).
[4] San Sebastian and Juana Diaz are two other names for this horizon. Pepino of Vaughan i
[5] May be early Quaternary.
[6] After C. A. Matley.
[7] After C. T. Trechmann and C. A. Matley.
[8] After A. Olsson (1922).
[9] May be higher stratigraphically.
[10] After Cushman; change from H. Douvillé (1915) and Vaughan (1918 and 1919).
[11] After H. Douvillé (1915, 1917, 1924).
[12] After Maury (1912).
[13] After Cossman (1913).
[14] Modified from Giraud (1918). The lower Burdigalian of this paper, I believe, should be
[15] After C. W. Cooke (1923).

Note—The United States Geological Survey has recently decided to comply with current Eu Lower Miocene. Although this decision is logical and proper, the boundary between the known in the West Indies and Central America; but, probably, most of the formations inc really Lower Miocene.

ELATION TABLE OF WEST INDIAN AND CENTRAL AMERICAN TERTIARY HORIZONS

Cuba	Jamaica		Eastern Mexico	Nicaragua	Panama and Costa Rica	Trinidad	Barbados	Martinique	L An
East of Guantanamo Bay	Manchioneal and Kingston formations [5]		Yucatan, Isthmus of Tehauntepec [5]		Toro limestone (Panama), Limon (Costa Rica)				
La Cruz marl and Matanzas marl	Bowden formation		Tuxpan formation; near Santa Rosa and other places, Isthmus of Tehuantepec	On the Pacific Coast near Brito		Well developed in Trinidad but not subdivided into units		Upper fossiferous Upper beds [10]	
	Near May Pen [5]				Gatun formation [6] Uscari formation [6]				Prob St.
Near Pinar del Rio, San Martin and other places		Limestone in Trelawny and elsewhere [5]	San Rafael formation (upper part)		Emperador limestone Culebra formation (upper part)	Present [11]	The Bissex Hill beds and underlying *Globigerina* limestone are of Oligocene age but cannot be more accurately correlated at present	Lower fossiliferous beds [14]	An form An St. St.
East of Guantanamo, near Matanzas, and other places	White Limestone	Limestone in Trelawny and elsewhere [5]	San Rafael formation (lower part) Meson formation		Culebra formation (lower part) Limestone at Tonosi	Present [11]		?Lower part of lower fossiliferous beds [14]	An form An St.
		Probably present	Alazan clay		Bohio conglomerate [9]	Perhaps present [11]			
Near Matanzas; Santa Lucia; Ponupo mine; many places in Cuba		Limestone in Trelawny and elsewhere [5]	Near Texas border: Fayette sandstone	Brito formation	Limestone with *Orthophragmina* on Haut Chagres and at David Panama [10]	San Fernando formation	?Scotland series		St. B ome sto Barth ?An
	Yellow limestone [7] (including Cambridge formation)		Yegua clay Cook Mountain formation		Eocene of Tonosi				
			Wilcox group			Eocene of Soldado Rock [13]			
			Midway formation						

ver Oligocene age.
bl. Repub. Haiti (1924).
r names for this horizon. Pepino of Vaughan is the same but Hill may not have intended so restricted a use (Vaughan, 1921).

(1915) and Vaughan (1918 and 1919).

Burdigalian of this paper, I believe, should be referred to the Aquitanian.

as recently decided to comply with current European usage and classify the American supposed equivalents of the Aquitanian as gical and proper, the boundary between the Upper Oligocene (Chattian) and the Lower Miocene (Aquitanian) is not definitely ca; but, probably, most of the formations indicated as Upper Oligocene in this table are of Aquitanian age and, therefore, are

RTINIQUE	LESSER ANTILLES	EASTERN UNITED STATES, Composite		EUROPEAN STAGE NAMES
		Caloosahatchee, and Waccamaw marls (nearly contemporaneous)		Astian Plaisancian
		Yorktown formation, and the Duplin and Choctawhatchee marls (nearly contemporaneous)		Pontian Sarmatian Helvetian
Upper siferous Upper eds [13]		St. Marys formation Choptank formation Calvert formation		Tortonian
	Probably in St. Croix	Alum Bluff group	Shoal River formation member	Helvetian
			Oak grove sand Chipola formation	Langhian
ower iliferous eds [14]	Anguilla formation Anguilla; St. Martin; St. Croix	Tampa formation		Aquitanian
wer part wer fos- ferous eds [14]	Antigua formation Antigua; St. Croix	Vicksburg group	Byram calcareous marl [4]	Chattian
			Glendon formation [15]	Rupelian
			Marianna limestone Red Bluff clay	Sannoisian
	St. Bartholomew limestone, St. Bartholomew ?Antigua	Jackson formation and Ocala limestone (contemporaneous)		Ludian (Priabonian) Bartonian
		Claiborne group	Gosport sand Lisbon formation Tallahatta formation	Auversian Lutetian
		Wilcox group	Hatchetigbee formation Bashi formation Tuscahoma formation Nanafalia formation	Ypresian Sparnacian
		Midway group	Naheola formation Sucarnochee clay Clayton limestone	Thanetian Montian

Sucarnochee clay.—E. A. Smith, L. C. Johnson, and D. W. Langdon: Op. sup. cit., page 186.

From Sucarnochee Creek, Alabama. Type section at Black Bluff, on the Tombigbee River, section 12, township 16, range 1 west, Sumter County, Alabama. The Sucarnochee clay immediately overlies the Clayton limestone and underlies the Naheola marl. It is richly fossiliferous, containing corals and mollusks.

Naheola formation.—E. A. Smith and L. C. Johnson: United States Geological Survey Bulletin 43, page 57; Smith, Johnson, and Langdon: Op. sup. cit., page 181.

From Naheola Landing, on Tombigbee River, Choctaw County, Alabama. The Naheola formation contains abundant fossils, especially corals and mollusks.

Wilcox group.—A. F. Crider: United States Geological Survey Bulletin 283, 1906, page 25.

From Wilcox County, Alabama, in which the different subdivisions of the group are well exposed. The "Lignitic stage" of G. D. Harris[21] is synonymous. In Alabama the Wilcox group is composed of four formations—the Nanafalia, Tuscahoma, Bashi, and Hatchetigbee—each containing an important bed of marine fossils. In Mississippi the deposits of similar age are of terrestrial origin and contain few or no marine fossils, but they do contain abundant plant remains. Therefore, in Mississippi a different set of names is used. These names are Ackerman, Holly Springs, and Grenada. Each of the seven names above enumerated are discussed in the following paragraphs.

Nanafalia formation.—T. H. Aldrich: Alabama Geological Survey Bulletin 1, 1886, page 58; Smith, Johnson, and Langdon: Op. sup. cit., page 170.

From Nanafalia Bluff, on Tombigbee River, Marengo County, Alabama. The formation constitutes the base of the Wilcox group and is overlain by the Tuscahoma formation, the next higher member of the group. It contains a rich marine fauna of corals and mollusks.

Tuscahoma formation.—D. W. Langdon: Bulletin of the Geological Society of America, volume 2, 1891, page 596; Smith, Johnson, and Langdon: Op. sup. cit., page 162 et seq.

From Tuscahoma Landing, Tombigbee River, Choctaw County, Alabama. (See Smith, Johnson, and Langdon, op. sup. cit., page 167, for detailed description.) This formation lies between the Nanafalia below and the Bashi above. It contains a large marine fauna of corals and mollusks.

Bashi formation.—A. Heilprin: Philadelphia Academy of Natural Sciences Journal, volume 9, 1884, pages 140, 144; Smith, Johnson, and Langdon: Op. sup. cit., page 154 et seq.

From Bashi Creek, Clarke County, Alabama. Typical exposure at Woods Bluff, Tombigbee River, just below the mouth of Bashi Creek. (See Smith,

[21] Amer. Paleontology Bull., vol. 2, 1897, p. 193 et seq.

Johnson, and Langdon, op. sup. cit., page 156, for detailed description.) The Bashi formation lies above the Tuscahoma and below the Hatchetigbee formation. It is richly fossiliferous and has yielded many species of corals, Bryozoa, and mollusks.

Hatchetigbee formation.—T. H. Aldrich: Alabama Geological Survey Bulletin 1, 1886, pages 10, 50; Smith, Johnson, and Langdon: Op. sup. cit., page 149 et seq.

From Hatchetigbee Bluff, Tombigbee River, Washington County, Alabama. (For detailed description of section, see Smith, Johnson, and Langdon, op. sup. cit., pages 149, 150.) The Hatchetigbee is the uppermost formation of the Wilcox group in Alabama, overlying the Bashi formation and underlying the Tallahatta formation, which is the basal formation of the Claiborne group. This formation bears a marine fauna which consists of a few corals and a considerable number of mollusks.

Ackerman formation.—E. N. Lowe: Mississippi Geological Survey Bulletin 10, 1913, page 23, and ibid., Bulletin 12, 1915, page 107; E. W. Berry: United States Geological Survey Professional Paper 91, 1916, page 43.

From Ackerman, Choctaw County, Mississippi. Type locality in the railroad cutting one mile east of Ackerman. The Ackerman is the lowest formation of the Wilcox group in Mississippi; it is non-marine, but contains a small fossil flora which has been described by Berry.

Holly Springs sand.—E. N. Lowe: Mississippi Geological Survey Bulletin 10, 1913, page 24, and ibid., Bulletin 12, 1915, page 108; Berry: Op. sup. cit., 1916, page 41.

From Holly Springs, Marshall County, Mississippi. "Typically developed at and for several miles east of Holly Springs" (Lowe, 1913). The Holly Springs sand is the middle formation of the Wilcox group in Mississippi; it is non-marine but contains a fair-sized flora, which has been described by Berry.

Grenada formation.—E. N. Lowe: Mississippi Geological Survey Bulletin 10, 1913, page 24, and ibid., Bulletin 12, 1915, page 108; Berry: Op. sup. cit., page 38.

From Grenada, Grenada County, Mississippi. "Typically exposed on Yalobusha River, near Grenada" (Lowe, 1915). The Grenada is the highest formation of the Wilcox group in Mississippi. It contains a large flora which has been described by Berry.

Claiborne group.—E. W. Hilgard: Geology and Agriculture of Mississippi, 1860, pages 3, 123 et seq.; Smith, Johnson, and Langdon: Op. sup. cit., page 122 et seq.; E. A. Smith: The underground water resources of Alabama. Alabama Geological Survey, 1907, pages 17-19.

From Claiborne Landing, Alabama River, Alabama. The Claiborne group in Alabama is composed of three formations, named from the lowest upward: Tallahatta formation, Lisbon formation, and Gosport sand. Because of inability to trace the three subdivisions of the Claiborne group over extensive areas outside Alabama, several local names have been applied, such as Mount

Selman, Cook Mountain, and Yegua in Texas; Saint Maurice and Yegua in Louisiana; and McBean in Georgia. The equivalents of the Lisbon and Tallahatta are collectively designated the "lower Claiborne" by several writers, to contrast the lower part of the group with the upper part, the Gosport sand, which is the famous "Claiborne ferruginous sand bed." The Claiborne group is very fossiliferous and it has supplied collections for many of the classic memoirs on American Eocene paleontology, which have extended in time from the days of Conrad and Lea to the present. There is no comprehensive report on the Foraminifera, but the other groups of marine invertebrates have received much attention, as follows: The corals by Vaughan, the echinoids by Clark and Twitchell, the Bryozoa by Canu and Bassler, the mollusks by Conrad, Lea, Aldrich, de Gregorio, Cossmann, Dall, Harris, and others. In places the beds are terrestrial and contain fossil plants, which have been described by Berry.

Tallahatta formation.—W. H. Dall: United States Geological Survey, Eighteenth Annual Report, part 2, 1898, page 344; E. A. Smith: The underground water resources of Alabama, 1907, pages 17, 18.

From Tallahatta Hills, Choctaw County, Alabama. The Tallahatta formation immediately overlies the Hatchetigbee formation and underlies the Lisbon formation. It is not very fossiliferous.

Lisbon formation.—G. D. Harris: American Journal of Science, third series, volume 47, 1898, page 304; Dall: Op. sup. cit., page 344; E. A. Smith: Op. sup. cit., page 18.

From Lisbon Landing on Alabama River, Clarke County, Alabama. (For detailed description see Smith, Johnson, and Langdon, op. sup. cit., pages 130, 131.) Harris includes the Lisbon in his "St. Maurice stage." The Lisbon formation is very fossiliferous, containing corals, echinoids, Bryozoa, and many mollusks.

Gosport sand.—E. A. Smith: Underground water resources of Alabama, 1907, pages 18, 19.

From Gosport Landing, on Alabama River, a few miles below Claiborne, Clarke County, Alabama. The Gosport greensand is the Claiborne ferruginous sand or simply sand bed. It immediately overlies the Lisbon formation and it underlies the Jackson. In the top of the Gosport at Claiborne there are a few plant-bearing layers. The fauna of the Gosport is very rich and comprises corals, echinoids, Bryozoa, and mollusks, all of which have been elaborately studied.

Mount Selman formation.—W. Kennedy: Texas Geological Survey, Third Annual Report, 1892, pages 52-54; A. Deussen: United States Geological Survey Water Supply Paper 335, 1914, page 51 et seq.

From Mount Selman, Cherokee County, Texas. For purposes of standards in geologic correlation the Mount Selman formation is not especially important, as it is only slightly fossiliferous, but it is the lowest formation of the Claiborne group in Texas and immediately underlies the Cook Mountain for-

mation, which is important. The Mount Selman is the approximate stratigraphic equivalent of the Tallahatta buhrstone.

Cook Mountain formation.—W. Kennedy: Op. sup. cit., 1892, pages 54-57; A. Deussen: Op. sup. cit., 1914, page 56 et seq.

From Cook Mountain, a hill in Houston County, Texas. The Cook Mountain overlies the Mount Selman and underlies the Yegua formation. It is very richly fossiliferous, containing corals, Bryozoa, and mollusks. Stratigraphically it is very nearly the equivalent of the Lisbon of Alabama and it represents the upper part of the Saint Maurice formation of Louisiana.

Yegua formation.—E. T. Dumble: Report on the brown coal and lignite of Texas. Texas Geological Survey, 1892, page 148 et seq.; A. Deussen: Op. sup. cit., 1914, page 65 et seq.

From Yegua Creek, a tributary of Brazos River, which forms the boundary between Burleson and Lee and Burleson and Washington counties, Texas. The Yegua is the uppermost formation of the Claiborne group in Texas, Louisiana, and Mississippi. It is mostly non-marine and has yielded only a few marine fossils, but it contains fossil plants which have been described by Berry. The upper part of the formation may be of Jackson age.

Saint Maurice formation.—G. D. Harris: Science, new series, volume 31, 1910, page 502; United States Geological Survey Bulletin 429, 1910, page 120 (footnote).

From Saint Maurice, Winnfield Parish, Louisiana. The Saint Maurice formation constitutes the lower part of the Claiborne group in Louisiana and is approximately the equivalent of the Mount Selman and Cook Mountain formations of Texas and the Tallahatta and Lisbon formations of Alabama. It contains a rich marine invertebrate fauna, which consists of Foraminifera, corals, Bryozoa, and mollusks.

Aquia formation.—W. B. Clark: Johns Hopkins University Circulars, volume 15, 1895, page 3; United States Geological Survey Bulletin 141, 1896, page 39 et seq.; W. B. Clark and G. C. Martin: Maryland Geological Survey, Eocene, 1901, pages 47, 58 et seq.; W. B. Clark and B. L. Miller: Virginia Geological Survey Bulletin number 4, 1912, page 90 et seq.

From Aquia Creek, a tributary of Potomac River, Stafford County, Virginia. The form of the name as first proposed was Aquia Creek "stage," but was later modified to Aquia formation. The type locality is along Aquia Creek near its mouth and near the tops of the divides east of Stafford. The Aquia formation is the oldest Eocene recognized in Maryland and Virginia, where it unconformably overlies the Cretaceous and is conformably overlain by the Nanjemoy formation. The Aquia and Nanjemoy formations together constitute the Pamunky group, which includes all the Eocene of Maryland and Virginia. The Aquia is divided into two members, the Piscataway indurated marl below and the Paspotansa greensand marl above. The formation is highly fossiliferous, the following groups of organisms being represented: Reptiles, fishes, ostracods, mollusks, brachiopods, Bryozoa, corals, and Foram-

inifera. The geologic age is about the same as that of the Tuscahoma formation in Alabama—that is, about middle Wilcox.

Nanjemoy formation.—W. B. Clark and G. C. Martin: Op. sup. cit., 1901, page 64 et seq.; W. B. Clark and B. L. Miller: Op. sup. cit., page 103 et seq.

From Nanjemoy Creek, a tributary of Potomac River, in Charles County, Maryland, just below Maryland Point. Type locality, along Nanjemoy Creek, especially near its head (see Clark and Martin, op. sup. cit., page 70). The Nanjemoy is the highest Eocene recognized in Maryland and Virginia. It conformably overlies the Aquia and is unconformably overlain by Miocene or younger deposits. Two members of the Nanjemoy are recognized. The lower member, the Potapaco clay member, is composed of greensand, often very argillaceous, in places gypseous. The upper member, the Woodstock greensand marl member, is characterized by fine, homogeneous greensands and greensand marls, which are less argillaceous than the underlying Potapaco. The fossils found in the Nanjemoy represent the following groups of organisms: Reptiles, fishes, ostracods, mollusks, Bryozoa, corals, Foraminifera, and a few plants. The age of the formation in terms of the Alabama section is probably upper Wilcox and lower Claiborne.

Jackson formation.—T. A. Conrad: Philadelphia Academy of Natural Sciences Proceedings, volume 7, 1856, page 257; E. W. Hilgard: Geology and Agriculture of Mississippi, 1860, page 128 et seq.

From Jackson, Mississippi, where there are (or were) numerous exposures along Pearl River and Moodys Branch. In Mississippi, Louisiana, and western Alabama the Jackson formation is the uppermost formation of the Eocene and carries a rich and varied marine invertebrate fauna, which comprises Foraminifera, corals, echinoids, Bryozoa, and mollusks. It grades into plant-bearing beds farther north in the Mississippi embayment and eastward it merges into the more purely calcareous Ocala limestone. Outside the area in which it exhibits its more typical aspect, formations equivalent in whole or in part to Jackson formation have received local names, as in the case of the Fayette sandstone of Texas and the Barnwell formation of eastern Georgia and western South Carolina.

Ocala limestone.—W. H. Dall: Wagner Free Institution of Sciences Transactions, volume 3, part 2, 1892, page 209; United States Geological Survey Bulletin 84, 1892, pages 103, 104; C. W. Cooke: United States Geological Survey Professional Paper 95, 1915, pages 107-117.

From Ocala, Florida, the area of its typical outcrop. The Ocala limestone is the uppermost Eocene in southeastern Alabama, Georgia, and Florida. It is characterized by great abundance of larger Foraminifera, echinoids, and Bryozoa, and there are some mollusks, of which species of *Pecten* are abundant.

West Indies—General statement.—The number of definitely applied Eocene formation names in the West Indies is relatively small, and of these those whose faunas are well enough known for use as correlation standards is still smaller. Therefore, only four names need to be considered, namely, Plaisance

limestone of Haiti, San Fernando formation of Trinidad, and the Saint Bartholomew limestone of Saint Bartholomew. Although only a descriptive term and not a formation name, the "Yellow limestone" of Jamaica will be included.

"Yellow limestone" of Jamaica.—J. G. Sawkins: Geology of Jamaica, 1869, page 24 (part); C. T. Trechmann: Geological Magazine, volume 60, 1923, page 337 et seq.

A descriptive term, no type locality. The recent studies of Trechmann indicate that the fauna of this formation is of Middle Eocene age and is of great importance for correlation purposes. R. T. Hill proposed two stratigraphic terms for certain deposits in Jamaica, the Catadupa beds and Cambridge formation,[22] but Hill so confused deposits of Cretaceous and Eocene age that it is doubtful if his names can be used. It is regrettable that Trechmann did not propose a new name, designate a type locality, and define the name stratigraphically and faunally.

Plaisance limestone.—T. W. Vaughan: Geological reconnaissance of the Dominican Republic, 1921, page 58; W. P. Woodring and J. S. Brown: Geology of the Republic of Haiti, 1924, page 99 et seq.

From the village of Plaisance, Republic of Haiti. Type locality at an altitude of 705 meters up the mountain side between Plaisance and Ennery, on the northeast slope of Mont Puilboreau. The Plaisance limestone is the lowest Eocene at its place of outcrop. It rests unconformably on volcanic rocks of probably Mesozoic age and there is a thin conglomerate at its base. The paleontology of the formation is summarized by Woodring (op. sup. cit.). The fauna comprises Foraminifera (especially *Dictyoconus*), corals, echinoids, and mollusks, and indicates Middle Eocene as the age. The formation appears to be the Haitian equivalent of the "Yellow limestone" of Jamaica, as restricted by Trechmann. The name Plaisance for a Tertiary formation in America is objectionable because of its prior use for a Pliocene formation in Italy, and it may, therefore, have to be abandoned.

San Fernando formation.—R. J. L. Guppy: Trinidad Scientific Association Proceedings, part 3, 1867, page 154 (see reprint of the American Paleontology Bulletin, volume 8, 1921, page 181; London Geological Society Quarterly Journal, volume 22, 1886, page 572.

From San Fernando, west coast of Trinidad, southeast margin of the Gulf of Paria. This horizon and its type locality are both famous. Much is due to R. J. L. Guppy for making them known. Since Guppy's earlier papers there has grown up a large bibliography on the San Fernando formation. Its fauna includes larger Foraminifera, echinoids, and brachiopods, which indicate an Upper Eocene geologic age very nearly the same, if not the same, as that of the Saint Bartholomew limestone.

Saint Bartholomew limestone.—T. W. Vaughan: Washington Academy of Sciences Journal, volume 8, 1918, page 271; United States National Museum Bulletin 103, 1919, page 193 et seq.

[22] R. T. Hill: Mus. Comp. Zool. Bull., vol. 34, 1899, pp. 57, 58, et seq.

From the Island of Saint Bartholomew, French West Indies. Type exposure along the shore, "northwest of Saint Jean Bay, for a distance of about one and a half miles. The rock is a hard bluish limestone, interbedded at its base with volcanic tuffs and water-worn volcanic fragments" (Vaughan, 1918). The formation contains a moderately large fauna, composed of larger Foraminifera, corals, echinoids, brachiopods, mollusks, and Crustacea, all of which has been more or less completely described. The geologic age is Upper Eocene, about the same horizon as the Priabonian of Italy.

OLIGOCENE

General statement.—The nomenclature of the standard stratigraphic subdivisions of the American Oligocene may best be discussed under three headings: The Atlantic and Gulf Coastal Plain, Central America and Mexico, and the West Indies. No sharp boundary between the Upper Oligocene and the Lower Miocene has yet been found in America. There is now and has been for years uncertainty as to whether certain beds should be classified as Upper Oligocene or Lower Miocene. Fortunately this is more a problem of nomenclature than of actual stratigraphic succession, but it needs to be emphasized that the nomenclatorial indecision results from incomplete knowledge, and that much more painstaking research is needed on the American formations that lie on and near the boundary of the Oligocene and Miocene.

The United States Geological Survey has recently decided to refer the supposed equivalents in America of the Aquitanian to the Lower Miocene. Although I concur in this decision, it reached me after this paper was in proof, and to make the text and tables conform to it would require more extensive changes in the proof than are practicable. The reader may make the needed changes, which are indicated in the text and at the bottom of tables numbers 2 and 3.

Atlantic and Gulf Coastal Plain—Work of C. W. Cooke.—C. Wythe Cooke has recently published a review of the stratigraphy of the Vicksburg group, which is very nearly, if not completely, synonymous with Oligocene in the southeastern United States. He recognizes, named in descending order, the following divisions:[88]

Byram calcareous marl.
Glendon formation.
Marianna limestone.
    Mint Springs calcareous marl member (at the top).
Red Bluff clay and Forest Hill sand (contemporaneous).

Three formations—the Tampa and Chattahoochee formations and the upper part of the Catahoula sandstone—which are correlated with the European Aquitanian, are here discussed under the Oligocene, although they should be classified as Lower Miocene. Each of these formations will be briefly considered.

[88] U. S. Geol. Survey Prof. Paper 133, 1923, p. 1.

Vicksburg group.—T. A. Conrad: Philadelphia Academy of Natural Sciences Proceedings, volume 3, 1846, pages 280, 281; E. W. Hilgard: Geology and Agriculture of Mississippi, 1860, page 138 et seq.; C. W. Cooke: Op. sup. cit., page 1.

From Vicksburg, Warren County, Mississippi, in and near which all the horizons of the group are exposed except the lowest, the Red Bluff clay, and its equivalent, the Forest Hill sand.

Red Bluff clay.—E. W. Hilgard: Op. sup. cit., page 136; C. W. Cooke: Op. sup. cit., page 2.

From Red Bluff, the type locality, on Chickasawhay River, 1½ miles below Shubuta, Wayne County, Mississippi. The Red Bluff constitutes the basal formation of the Vicksburg group and overlies the upper beds of the Jackson formation. It contains a rich marine invertebrate fauna, which is composed of Foraminifera, corals, echinoids, Bryozoa, and mollusks.

Forest Hill sand.—C. W. Cooke: Washington Academy of Sciences Journal, volume 8, 1918, page 192; and United States Geological Survey Professional Paper 133, 1923, page 1.

From Forest Hill, 5½ miles southwest of Jackson, Mississippi. The Forest Hill sand is a non-marine equivalent of the Red Bluff clay. It contains petrified wood, leaves, and other plant remains, but few identifiable specimens have been found. However, it is possible that this formation may yet supply material for knowledge of the Lower Oligocene flora of the Coastal Plain.

Marianna limestone.—G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, 1910, page 52 et seq.; C. W. Cooke: United States Geological Survey Professional Paper 95, 1915, page 109 et seq.; and ibid., Professional Paper 133, 1923, pages 2-3.

From Marianna, Florida. Type locality, Marianna, Florida, east edge of the town, particularly a quarry from which the limestone is taken for building purposes. The Marianna limestone lies below the Glendon formation and rests on the Red Bluff clay or, at the type locality, on the Ocala limestone, where a thin bed in its lower part contains glauconite and may represent the Red Bluff clay. This rock, in considerable areas in Alabama and Florida, is known as "chimney rock" because it is so largely used in the construction of chimneys for dwelling houses. The fauna comprises larger Foraminifera, *Lepidocyclina mantelli*, echinoids, *Clypeaster rogersi*, and mollusks, *Pecten poulsoni*.

Mint Spring calcareous marl member.—C. W. Cooke: Washington Academy of Sciences Journal, volume 8, 1918, page 195; and United States Geological Survey Professional Paper 133, 1923, pages 2, 3.

Mint Spring calcareous marl member.—"From Mint Spring Bayou, a small stream entering Centennial Lake just south of the National Cemetery at Vicksburg. The strata to which the name is applied are exposed beneath a waterfall in the lower course of the stream" (Cooke, op. sup. cit., 1918). In western Mississippi the Mint Spring calcareous marl replaces the "Chimney

Rock" facies of the Marianna limestone. It lies above the Forest Hill sand and below the Glendon formation. The fauna of the Mint Spring marl contains many Foraminifera, a few corals, and 160 species of mollusks, and therefore is paleontologically important.

Glendon formation.—C. W. Cooke: Washington Academy of Sciences Journal, volume 8, 1918, page 195; and United States Geological Survey Professional Paper 133, 1923, page 3, and page 4 et seq.

From Glendon, a village on the Southern Railway, Clarke County, Alabama. The Glendon formation was originally described as a member of the Marianna limestone, but Cooke was later (1923) led to accord it formational rank, stating that, "inasmuch as beds of Glendon age are now known to have a wider distribution than the typical Marianna, to contain a large and characteristic fauna, and to transgress older formations, it seems advisable to regard the Glendon as of formational rank." The Glendon lies above the typical Marianna limestone and beneath the Byram calcareous marl. The fauna comprises larger Foraminifera, corals, echinoids, and mollusks and is moderately large. It is equivalent in age to the Antigua formation, or more certainly the lower part of the Antigua formation, of Antigua, British West Indies, and is the correlative of the Rupelian (Stampian) of Europe. The Glendon formation marks an important horizon, for it appears to furnish a definite tie with the Oligocene of Europe.

Byram calcareous marl.—C. W. Cooke: Washington Academy of Sciences Journal, volume 8, 1918, pages 196, 197; United States Geological Survey Professional Paper 129, 1922, page 79 et seq.; and Ibid., Professional Paper 133, 1923, page 3.

From Byram, Pearl River, Hinds County, Mississippi. Col. T. L. Casey[94] used the expression "Byram substage" in 1901, but did not adequately define the term and erroneously placed the "substage" in the stratigraphic sequence. The use of Byram, therefore, as a well defined stratigraphic term was initiated by Cooke. The Byram marl is the uppermost formation of the Vicksburg group; it is typically exposed at Byram and in the upper part of the bluffs at Vicksburg, Mississippi. The fauna is a large one, containing Foraminifera, corals, Bryozoa, and mollusks. It is preeminently the horizon of *Lepidocyclina supera* (Conrad).

Tampa formation.—W. H. Dall: Wagner Free Institution of Sciences, volume 3, 1892, page 209; G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, 1910, page 84 et seq.; and United States Geological Survey Water Supply Paper 319, 1913, page 102 et seq.; W. H. Dall: United States National Museum Bulletin 90, 1915; C. W. Cooke: United States Geological Survey Professional Paper 133, 1923, page 9, text and table.

From Tampa, Florida. A discussion of the means whereby the stratigraphic position of the Tampa formation has been ascertained would require more space than is permissible in this summary paper; therefore the statements

[94] Phila. Acad. Nat. Sci. Proc., vol. 53, 1901, pp. 517, 518.

regarding the subject must be more categorical than is desired. At Tampa there are two noteworthy beds—a lower one, in which the famous silicified fossils of the "silex bed" are found, and an immediately overlying limestone bed, which contains a fauna smaller than, but very similar to, that of the "silex bed." The equivalent of the limestone bed has been recognized south of Tallahassee, in Wakulla County, and at River Junction, in Gadsden County, Florida. The exposure at River Junction is referred to the Chattahoochee formation, which passes immediately under the Chipola formation of the Alum Bluff group. The horizon of the Tampa formation is between the Chipola formation, which is generally considered of Langhian (Burdigalian) age, and the Byram calcareous marl, which is apparently of Chattian age. The Tampa formation is richly fossiliferous, especially in corals and mollusks. The limestone contains numerous Foraminifera known as "*Orbitolites*" *floridanus* (Conrad), which probably belongs to the genus *Sorites*.

Chattahoochee formation.—D. W. Langdon: American Journal of Science, third series, volume 38, 1889, page 322 et seq.; W. H. Dall and J. Stanley-Brown: Bulletin of the Geological Society of America, volume 5, 1894, page 162 et seq.; G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, 1910, page 74 et seq.; and United States Geological Survey Water Supply Paper 319, 1913, page 93 et seq.; C. W. Cooke: United States Geological Survey Professional Paper 133, 1923, page 9 (table).

From Chattahoochee, a village and post-office near River Junction, Gadsden County, Florida. Type locality at old Chattahoochee Landing, on Apalachicola River, Gadsden County, Florida, the river landing for the village of Chattahoochee. The Chattahoochee is the next formation immediately below the Chipola formation of the Alum Bluff group and is contemporaneous with the Tampa formation; but, although Chattahoochee formation is the older name, as it is not nearly so fossiliferous as the Tampa formation, it should probably be dropped and Tampa formation retained in the stratigraphic nomenclature of the Atlantic and Gulf Coastal Plain.

Catahoula sandstone.—A. C. Veatch: Louisiana Geological Survey Bulletin 1, part 2, 1905, pages 84, 85, 90; and United States Geological Survey Professional Paper 46, 1906, pages 42, 43; G. C. Matson and E. W. Berry: Ibid., Professional Paper 98, 1916, pages 209-251; C. W. Cooke: United States Geological Survey Professional Paper 133, 1923, page 9 (table).

From Catahoula Parish, Louisiana. The name Catahoula was introduced by Veatch for the typical "Grand Gulf" of Grand Gulf, on the Mississippi River, Claiborne County, Mississippi. The older name, "Grand Gulf," had been so extended in its application that it included many different formations and horizons. In Catahoula Parish, Louisiana, there are, directly across the Mississippi Valley, the counterparts of the exposure at Grand Gulf. The formation is mostly or entirely of terrestrial origin and is the stratigraphic equivalent of the Lower Miocene Tampa and Chattahoochee formations and the upper Byram and middle Oligocene Glendon formations. It contains a considerable fossil flora which has been described by Berry.

Central America and Mexico—General statement.—Although a considerable number of stratigraphic terms have been applied to the Oligocene (and possibly Lower Miocene) deposits of Central America and a few to those of Mexico, the paleontologic characterization of most of them is not adequate for the utilization of them as standards in correlation. Therefore only five formations will be considered—the Culebra formation and Emperador limestone of Panama and the Alazan, Meson, and San Rafael formations of Mexico.

Culebra formation.—R. T. Hill: Museum of Comparative Zoology Bulletin, volume 28, page 192 et seq.; E. Howe: American Journal of Science, fourth series, volume 26, 1908, page 222 et seq.; D. F. MacDonald: United States Bureau of Mines Bulletin 86, 1915, pages 21, 22; and United States National Museum Bulletin 103, 1919, page 527; T. W. Vaughan: United States National Museum Bulletin 103, 1919, page 550 et seq.

From the village of Culebra, Panama Canal Zone, the site of the deepest part of the cutting along the Panama Canal. The cut is now known as Gaillard Cut. MacDonald recognizes an upper and a lower part of the Culebra formation. Near the top, *Miogypsina cushmani* Vaughan, n. sp., is very abundant; at a lower horizon *Lepidocyclina canellei* and *L. vaughani* are common; and apparently still lower the horizon of the lower part of the Antigua seems to be represented.

Emperador limestone.—D. F. MacDonald: United States Bureau of Mines Bulletin 86, 1919, page 531; T. W. Vaughan: United States National Museum Bulletin 103, 1915, page 24; and United States National Museum Bulletin 103, 1919, page 556 et seq.; and National Academy of Sciences Proceedings, volume 9, 1923, page 254.

From a Spanish substitute for the English name of the village of Empire, in the Panama Canal Zone. R. T. Hill had used the preoccupied name Empire limestone for the formation. The Emperador limestone is stratigraphically above the Culebra formation. It contains a fairly rich coral fauna and some Foraminifera, echinoids, Bryozoa, mollusks, and Crustacea. *Lepidocyclina vaughani* was not found in the Emperador limestone, as was at first supposed by MacDonald, but *L. miraflorensis* apparently does occur in it. (See Vaughan, op. sup. cit., 1923.) The question as to whether the uppermost part of the Culebra formation, in which *Miogypsina cushmani* is so abundant, and the Emperador limestone, which also contains *Miogypsina*, are correctly correlated with the European Aquitanian needs further consideration. The possibility of their being of Langhian (Burdigalian) age is not excluded.

Alazan clay.—E. T. Dumble: California Academy of Sciences Proceedings, volume 8, 1918, page 141 et seq.

From the village of Alazan, Tuxpan County, Vera Cruz, Mexico. The type locality is on Rio Buena Vista, just below the crossing of the road from Alazan to Moyutla. In the autumn of 1920 I made a rather large collection of fossils from this locality. Smaller Foraminifera are very abundant, but seem not to be of critical value for correlation purposes, but the molluscan fauna, which is moderately rich, does furnish decisive evidence. The mollusks have been described in detail by C. W. Cooke in a manuscript not yet pub-

lished and indicate that the Alazan is of Vicksburg age. Since it underlies the Meson, which is of Middle Oligocene age, the Alazan is of Lower Oligocene age. Although the paleontologic data have not yet been published, it is expected that they soon will be, and that the Alazan will then become one of the standard horizons in the correlation of the American Tertiary formations.

Meson formation.—E. T. Dumble: Op. sup. cit., page 147.

From Meson, Tuxpan County, Vera Cruz, Mexico. Type locality, "in the valleys lying between Moralillo and Meson, on the trail leading from Tamiahua to Alazan" (Dumble, op. et loc. sup. cit.). The Meson is a yellowish impure limestone, particularly characterized by an enormous abundance of *Lepidocyclina gigas* var. *mexicana* Cushman and *L. undosa* Cushman. There are other Foraminifera, echinoids, mollusks, and Crustacea. Only meager data have as yet been published on the paleontology of the Meson, but it is expected soon to publish more extensive information. The formation is approximately the equivalent of the Glendon formation of Alabama, Florida, and Georgia, and of at least the lower part of the Antigua formation of Antigua.

San Rafael formation.—E. T. Dumble: Op. sup. cit., page 147 et seq.; T. W. Vaughan: United States National Museum Bulletin 103, 1919, pages 206, 207, 582.

From San Rafael, on Zarzizal Creek, Tamaulipas, Mexico, 65 miles north of Tampico. Type locality, the hills, 300 to 400 feet high, four miles east of San Rafael. A small coral fauna collected by Dumble was described by me in my paper cited above. In 1920 I collected the same fauna at a number of places in eastern Tamaulipas and Vera Cruz, from Arbol Grande, near Tampico, at the north, to Zacamixtle, at the south. At Arbol Grande *Lepidocyclina gigas* (rare), *L. tournoueri* (abundant), *L.* sp. aff. *L. morgani* (abundant), and *L. cancellei* (common) occur in close relations to the coral fauna. It is doubtful if the San Rafael can be separated as a distinct formation from the Meson; it seems rather to represent a facies of the upper part of the Meson and is probably of Aquitanian age, but may be a little older.

West Indies—General statement.—Only a small number of stratigraphic terms applied to the West Indian Oligocene need consideration, for unless the paleontologic content is rather large the formations can not be used as standards for correlations. The two principal formations are the Middle Oligocene Antigua and the uppermost Oligocene Anguilla formations. The Porto Rican Oligocene faunas are moderately rich, and the work of Dr. Carlotta J. Maury and Dr. Bela Hubbard on the mollusks, that of Dr. R. T. Jackson on the echinoids, and mine on the corals deserves mention. Deposits of Oligocene age in the Dominican Republic are discussed by Vaughan, Cooke, and others in their report on that republic, in the Republic of Haiti by Woodring and others in their report on Haiti, in Jamaica by Matley, in Trinidad by Douvillé, and there is other information which can not be summarized here.

Antigua formation.—J. W. Spencer: London Geological Society Quarterly Journal, volume 57, 1901, page 496 et seq.; T. W. Vaughan: United States National Museum Bulletin 103, 1919, pages 199-203, 259, 260; and Carnegie

Institution of Washington Publication 306, 1922, pages 112, 113, 121; R. T. Jackson: Carnegie Institution of Washington Publication 306, 1922, page 8.

From the Island of Antigua, British West Indies. No specific type locality has been designated, but it may be said that the formation immediately overlies a deposit of gravel exposed from place to place from Willoughby Bay northwestward to Cassada Gardens, and that the gravel in turn overlies the Antiguan tuffs. In the lower part of the formation larger Foraminifera, corals, echinoids, mollusks, and a few Bryozoa are found.[95] The upper limits of the formation have not been defined. It appears that more than one horizon is represented in the Antigua formation, and that a very carefully measured stratigraphic section, with collections from the different beds, is needed. Most of the collections made by me come from near the base of the formation. The coral fauna, which I have compared with the Rupelian corals of Italy, therefore represents the lower part of the formation. The upper part of the formation may represent a younger horizon. In fact, it seems that the deposits on Half Moon Bay are the equivalent of the lower part of the Culebra formation of the Panama Canal Zone.[96]

Anguilla formation.—T. W. Vaughan: Washington Academy of Sciences Journal, volume 8, 1918, page 271; United States National Museum Bulletin 103, 1919, pages 209, 210, 262; Carnegie Institution of Washington Publication 306, 1922, pages 113, 114.

From the Island of Anguilla, British West Indies. Type locality, southeast and south shore of Crocus Bay, which is about the middle of the coastline, on the northwest side of the island, where the formation is exposed to a thickness of about 200 feet and unconformably overlies basic igneous rock. The material of the formation comprises calcareous clay, argillaceous limestone, and more or less pure limestone. The Anguilla formation is richly fossiliferous and most of its paleontology has been described in some detail.[97] The Anguilla formation is the correlative of the Emperador limestone of the Panama Canal Zone. It is partly characterized by great abundance of *Miogypsina antillea* (Cushman),[98] with which I found no *Lepidocyclina*. Continued study of the West Indian Tertiary formations leads me to doubt that the Anguilla is so old as the European Aquitanian; it may be of Langhian (Burdigalian) age.

[95] For description of some of the foraminifera by Cushman, of the mollusks by Cooke, and the bryozoa by Canu and Bassler, see Carnegie Inst. Washington Pub. 281, 1919. Howe describes a few calcareous algæ in the same volume. Jackson has described the echinoids, op. sup. cit., and I have summarized the coral faunas, op. sup. cit., 1919.

[96] T. W. Vaughan: Nat. Acad. Sci. Proc., vol. 9, 1923, p. 255.

[97] In Carnegie Inst. Washington Pub. 291, 1919, calcareous algæ by M. A. Howe, foraminifera by J. A. Cushman, bryozoa by F. Canu and R. S. Bassler, mollusks by C. W. Cooke, and crustacea by M. J. Rathbun. In Carnegie Inst. Washington Pub. 306, 1922, echinoids by R. T. Jackson, with a discussion of their stratigraphic significance by T. W. Vaughan. In U. S. Nat. Mus. Bull. 103, corals, partial account by T. W. Vaughan. In U. S. Geol. Survey Prof. Paper 129-B, the molluscan genus *Orthaulax* by C. W. Cooke, revised identification of species from Anguilla.

[98] In U. S. Nat. Mus. Bull. 103, p. 210, I mention *Heterosteginoides* (a synonym of *Miogypsina*) as occurring in Antigua. This is an error. *Heterosteyina antillea*, not *Heterostegínoides antillea*, was collected by me in Antigua.

MIOCENE

General statement.—During the last twenty-five years investigations of the American Miocene have been prosecuted with so much vigor that knowledge of it is now considerable and the number of well marked zones or horizons is very large. The nomenclature of the more important horizons will be discussed under three areal subdivisions—Atlantic and Gulf Coastal Plain, Central America and Mexico, and the West Indies.

Atlantic and Gulf Coastal Plain—General statement.—The following names will be considered: The Alum Bluff group, with its three formations—the Chipola formation, the Oak Grove sand, and the Shoal River formation; the Calvert,[99] Choptank,[99] Saint Marys,[99] Yorktown, Duplin, and Choctawhatchee formations.

Alum Bluff group.—W. H. Dall and J. Stanley-Brown: Bulletin of the Geological Society of America, volume 5, 1894, page 165; G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, page 91 et seq.; E. W. Berry: United States Geological Survey Professional Paper 98-E, 1917; T. W. Vaughan: United States National Museum Bulletin 103, 1919, pages 219, 220, 572-574.

From Alum Bluff, a bluff on the east side of Apalachicola River, in Liberty County, Florida, about 25 miles below River Junction, Florida. Matson and Clapp modified Dall and Stanley-Brown's original definition of the term Alum Bluff formation so as to include under one name the Chipola marl, the Oak Grove sand, and a recently discovered deposit, the Shoal River marl. The Alum Bluff group overlies the Chattahoochee formation and is unconformably overlain by the late Miocene Choctawhatchee marl. The deposits composing it are enormously rich in marine fossils, particularly mollusks, to the description of which much, if not most, of Dall's great work on the Tertiary fauna of Florida is devoted,[100] but the description of the molluscan fauna is not yet complete. A large memoir by Julia Gardner, in which the Alum Bluff is elevated to the rank of a group, divided into three formations, the Chipola, Oak Grove, and Shoal River, is in course of publication. The latter classification has been adopted by the United States Geological Survey. Besides mollusks, the formation contains some fossil plants, described by Berry (op. sup. cit.); smaller Foraminifera, described by Cushman; corals, summarized by Vaughan; Bryozoa, described by Canu and Bassler, and fossil vertebrates, described by Sellards; for references, see Vaughan, op. sup. cit. The lower and middle formations of the Alum Bluff group seem to be clearly of Langhian (Burdigalian) age: the upper part, the Shoal River marl, is assigned to the Helvetian.

Chipola formation.—W. H. Dall: United States Geological Survey Bulletin 84, 1894, page 122; G. C. Matson and F. G. Clapp: Op. sup. cit., page 91; G. C. Matson: Op. sup. cit., page 117 et seq.

From Chipola River, Florida. Type locality at McClelland's farm, near

[99] Names first proposed, without definition, by G. B. Shattuck. Science, N. S., vol. 15, 1902, p. 906.

[100] Wagner Free Inst. Sci. Trans., vol. 3, 6 pts., 1890-1903, 1654 pp., 60 pls.

Bailey's Ferry, in the northern part of Calhoun County, Florida. The Chipola is the basal formation of the Alum Bluff group. It immediately overlies the Chattahoochee formation and is older than the Oak Grove sand of the Alum Bluff group. It is very fossiliferous, all the groups of marine organisms enumerated in the foregoing paragraph being represented.

Oak Grove sand.—W. H. Dall: Wagner Free Institution of Sciences Transactions, volume 3, part 6, 1903, page 1588 et seq:; G. C. Matson and F. G. Clapp: Op. sup. cit., page 104; G. C. Matson: Op. sup. cit., pages 119, 120.

From the village of Oak Grove, Okaloosa County, Florida. Type locality, on Yellow River, just south of the bridge across the river, east of Oak Grove. As stated above, the Oak Grove sand is the median formation of the Alum Bluff group. It contains a rich and varied marine fauna.

Shoal River formation.—G. C. Matson and F. G. Clapp: Op. sup. cit., page 104 et seq.; G. C. Matson: Op. sup. cit., pages 120, 121.

From Shoal River, Walton County, Florida. Type locality at Shell Bluff, section 4, township 3 north, range 21 west, on Shoal River. The Shoal River is stratigraphically higher than the Oak Grove sand. It is rich in fossils, especially mollusks, which have been studied and described by Julia Gardner in a memoir in course of publication. The Shoal River is assigned to the Middle Miocene (Helvetian).

Calvert formation.—W. B. Clark: Maryland Geological Survey, Miocene, 1904, pages lxix et seq. and xciv et seq.; E. W. Berry: United States Geological Survey Professional Paper 98-F, 1916.

From Calvert County, Maryland. Type locality, Calvert Cliffs, along the west side of Chesapeake Bay, from Chesapeake Beach to Drum Point. The Calvert is the lowest formation of the Miocene in Maryland and Virginia. It contains a large marine fauna, which comprises mammals, birds, reptiles, fishes, crabs, barnacles, ostracods, mollusks, brachiopods, Bryozoa, hydroids, corals, Foraminifera, and diatoms. Fossil land plants, described by Berry (op. sup. cit.), have been found at Richmond, Virginia. Berry correlates the Calvert with the Tortonian of Europe.

Choptank formation.—W. B. Clark: Op. sup. cit., 1904, pages lxxviii et seq. and xciv et seq.

From Choptank River, eastern Maryland. Type locality, on the northern bank of Choptank River, a short distance below Dover Bridge, Talbot County. The Choptank formation is the middle of the three Miocene formations recognized in Maryland. It contains many fossils, which represent the following groups of organisms: mammals, fishes, crabs, barnacles, ostracods, mollusks, brachiopods, Bryozoa, echinoids, corals, and Foraminifera.

Saint Marys formation.—W. B. Clark: Op. sup. cit., 1904, pages lxxxii et seq. and xciv et seq.

From Saint Marys County, Maryland. Type locality, along Saint Marys River, in the vicinity of Saint Marys City. The Saint Marys is the uppermost

formation of the Maryland Miocene. The following groups of organisms are represented by fossils in it: mammals, fishes, crabs, barnacles, mollusks, brachiopods, Bryozoa, ophiuroids, hydroids, and Foraminifera.

Yorktown formation.—W. B. Clark and B. L. Miller: Virginia Geological Survey, Geological Series, Bulletin 2, 1906, page 19; and Ibid., Bulletin 4, 1912, page 158 et seq.

From Yorktown, Virginia. Type locality, exposures in the cliffs on the southwest side of York River, at Yorktown. The Yorktown formation is the formation next younger than the Saint Marys and is the uppermost Miocene in Virginia. The fossils found in it represent mammals, crabs, barnacles, mollusks, and brachiopods. The Yorktown is considered a more northerly equivalent of the Duplin marl of the Carolinas.

Duplin marl.—W. H. Dall: United States Geological Survey, Eighteenth Annual Report, part 2, 1898, page 338 and table; and Wagner Free Institution of Sciences Transactions, volume 3, part 6, 1903, page 1598 et seq.; W. B. Clark and B. L. Miller: North Carolina Geological and Economic Survey, volume 3, 1912, page 236 et seq.

From Duplin County, North Carolina. Type locality, Natural Well, two miles southeast of Magnolia, Duplin County. The Duplin is the highest formation of the Miocene in North and South Carolina. It is very fossiliferous, remains of the following groups of organisms having been collected: Foraminifera, corals, echinoids, brachiopods, Bryozoa, and mollusks.

Choctawhatchee marl.—G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, page 114 et seq.; G. C. Matson: United States Geological Survey Water Supply Paper 319, page 127 et seq.; W. C. Mansfield: United States National Museum Proceedings, volume 51, 1916, page 599 et seq.; T. W. Vaughan: United States National Museum Bulletin 103, 1919, page 576.

From Choctawhatchee Bay, Walton County, Florida. Type locality, vicinity of Red Bay, a small settlement about 18 miles southeast of De Funiak Springs, Walton County. The Choctawhatchee marl overlies the Alum Bluff group, from which it is separated by a distinct erosion interval, and represents the youngest Miocene as yet recognized in Florida. The fauna is a fairly large one, comprising Foraminifera, corals, Bryozoa, and mollusks, and is very similar to that of the Duplin marl. Because of this similarity I have expressed the opinion that the Choctawhatchee is of very nearly the same, if not of the same, age as the Duplin marl.

Central America and Mexico—General statement.—Only three names need be considered for deposits of clearly Miocene age in Central America and Mexico. They are the Uscari, Gatun, and Tuxpan formations.

Uscari formation.—A. Olsson: American Paleontological Bulletin, volume 9, 1922, page 10.

From Uscari Creek, Talamanca Valley, eastern Costa Rica. The Uscari formation, according to Olsson, is unconformably overlain by the Gatun for-

mation. It consists principally of soft, dark-colored shales, which contain a fauna of smaller Foraminifera, fish scales, echinoid spines, and a few mollusks. No Lepidocycline Foraminifera were found. Although the Uscari formation has not been sufficiently defined paleontologically for the horizon to be identified outside the area of typical outcrop, it appears to be important as indicating a Miocene horizon below the Gatun in Costa Rica.

Gatun formation.—R. T. Hill: Museum of Comparative Zoology Bulletin, volume 28, 1898, page 206; W. H. Dall: United States Geological Survey, Eighteenth Annual Report, part 2, 1898, page 344; E. Howe: American Journal of Science, fourth series, volume 26, 1908, page 219; D. F. MacDonald, United States Bureau of Mines Bulletin 86, 1915, page 25; and United States National Museum Bulletin 103, 1919, pages 531, 532, 542-544; T. W. Vaughan: United States National Museum Bulletin 103, pages 558 et seq. and 586 et seq.

From Gatun, a station on the Panama Railroad between Colon and Panama. The exposures in the vicinity of Gatun are described by MacDonald, op. sup. cit., 1919, and my paper cited above gives a summary to date, 1919, of what was known of the paleontology of the formation in its type area. There are several beds in the Gatun and it may be subdivided into several zones. The fossils found in the Gatun include plants, Foraminifera, echinoids, mollusks, Crustacea, and sharks' teeth. The molluscan fauna is decidedly rich, including at present 129 identified species, a number which will probably be considerably increased when the large collections made by Doctor MacDonald and me have been critically studied. The present trend of paleontologic opinion is to correlate the Gatun with the Helvetian of Europe—an opinion really dating from 1898, when H. Douvillé correlated the upper part of the Gatun with the Helvetian.

Tuxpan formation.—E. T. Dumble: Science, new series, volume 33, 1911, page 234; California Academy of Sciences Proceedings, volume 8, 1918, page 149.

From the city of Tuxpan (also spelled Tuxpam), Vera Cruz, Mexico, where the formation is typically exposed. Unfortunately, almost nothing has been published on the paleontology of the Tuxpan formation. This deficiency, I trust, may soon be supplied by the publication of accounts of moderate-sized collections that have come into my hands through the Aguila Oil Company. The fauna at Tuxpan, the type locality, includes larger Foraminifera, echinoids, and mollusks. *Clypeaster meridanensis* (Mich.), identified by R. T. Jackson, is an abundant and apparently characteristic echinoid. Just east of Zacamixtle, at the Azteca Incline, the Tuxpan overlies the San Rafael formation, from which it is separated by a disconformity. After the publication of the data on the paleontology of the Tuxpan, the formation will become important in the general correlation of the American Tertiary formations.

West Indies—General statement.—Because of the great sections exposed, the standards for the general treatment of the West Indian Miocene will be taken from the Dominican Republic and the Republic of Haiti, supplemented by the exposure of the richly fossiliferous marl at Bowden, Jamaica. Although names have been applied to Miocene deposits in other West Indian

Islands, only the islands of Haiti and Jamaica need consideration in this connection. The names for the Dominican Republic, named in ascending order, are Baitoa, Cercado, and Gurabo formations, Mao Adentro limestone, Mao clay, and Cerros de Sal formation; for the Republic of Haiti, Madame Joie formation, Thomonde formation and the Maïssade tongue, and the Las Cahobas formation; for Jamaica, the Bowden formation. Paleontologic summaries to date for the Dominican Republic[101] and Haiti[102] are given in the volumes cited below. W. P. Woodring has in press, at the Carnegie Institution of Washington, a monographic account of the molluscan fauna of the Bowden formation of Jamaica.

Yaque group.—C. W. Cooke: Bulletin of the Geological Society of America, volume 31, 1920, page 219; Geological reconnaissance of the Dominican Republic, 1921, page 65 et seq.; T. W. Vaughan and W. P. Woodring: Idem., page 96 et seq.

From the two Yaque rivers of the Dominican Republic. In the northern part of the Republic the group consists of the Baitoa formation, the Bulla conglomerate, the Cercado and Gurabo formations, the Mao Adentro limestone, and the Mao clay. In the southern part of the Republic all the Miocene exposed along Rio Yaque del Sur is referred to it without subdivision into formation. The name is a general one and will probably be used very little for correlation purposes.

Artibonite group.—W. P. Woodring: Stratigraphy, structure, and possible oil resources of the Miocene rocks of the Central Plain, Haiti. Haiti, Department of Publication Works Bulletin, 1922, page 6; W. P. Woodring and J. S. Brown: Geology of the Republic of Haiti, 1924, page 161 et seq.

From Rivière Artibonite, Central Plain, Haiti. Artibonite group is a comprehensive name for the Miocene of the Central Plain of Haiti and includes the Madame Joie formation, the Thomonde formation and the Maïssade tongue, and the Las Cahobas formation.

Baitoa formation.—C. W. Cooke: Bulletin of the Geological Society of America, volume 31, 1920, page 219; and Geological reconnaissance of the Dominican Republic, page 66; T. W. Vaughan and W. P. Woodring: Geological Reconnaissance of the Dominican Republic, 1921, pages 96, 113, 114.

From Baitoa, a village on Rio Yaque del Norte, on the road from Santiago de los Caballeros to Jarabacoa. Type locality, bluff at Baitoa. The Baitoa formation is the lowest known fossiliferous Miocene in the Dominican Republic. It unconformably overlies an Oligocene formation designated the Tabera formation. The fauna contained in the Baitoa comprises corals, Bryozoa, and mollusks. The fauna appears to be clearly of Langhian (Burdigalian) age and the correlative of the Chipola formation of Florida.

[101] T. W. Vaughan, W. Cooke, D. D. Condit, C. P. Ross, W. P. Woodring, and F. C. Calkins: A geological reconnaissance of the Dominican Republic. Dominican Rep. Geol. Survey, Mem., vol. 1, 1921, 268 pp., 23 pls.

[102] W. P. Woodring, J. S. Brown, and W. S. Burbank: Geology of the Republic of Haiti. Repub. of Haiti Geol. Survey, 631 pp., 40 pls., 37 text figs., 1924.

Madame Joie formation.—W. P. Woodring: Stratigraphy, structure, and possible oil resources of the Central Plain [of Haiti]. Publication Department of Public Works of Haiti, 1922, pages 6, 7; W. P. Woodring and J. S. Brown: Geology of the Republic of Haiti, 1924, page 162 et seq.

From Madame Joie, a village about 10 kilometers west of Maïssade, Haiti. Type locality, at the foot of Morne Madame Joie, about one kilometer southwest of the village, where the formation crops out at the base of the mountains, along the western and southern margins of the plain. The Madame Joie formation is the oldest Miocene formation exposed in the Central Plain of Haiti. It overlies, with no apparent unconformity, Upper Oligocene limestone, but the actual contact was not seen. The small fossil fauna collected in it includes corals and mollusks. The formation is of either Aquitanian of Langhian age; probably Lower Langhian.

Thomonde formation.—W. F. Jones: Journal of Geology, volume 26, 1918, pages 736, 737; W. P. Woodring and J. S. Brown: Op. sup. cit., page 165 et seq.

From Thomonde, a village in the Central Plain of Haiti. Type locality, the vicinity of Thomonde. The Thomonde formation conformably overlies the Madame Joie formation. It contains a very large marine fauna which consists of Foraminifera, corals, mollusks, and decapod Crustacea. The number of species of mollusks, including the Maïssade tongue, exceeds 350 species. The Thomonde formation, according to Woodring, is apparently the equivalent of part of the Yaque group of the San Juan Valley and the valley of Rio Yaque del Sur, in the Dominican Republic, and he regards it as of Langhian, probably middle Langhian, age.

Maïssade tongue of the Thomonde formation.—W. F. Jones: Op. sup. cit., page 739 et seq.; W. P. Woodring and J. S. Brown: Op. sup. cit., pages 168 et seq. and 191 et seq.

From the village of Maïssade, Central Plain, Haiti. Type locality, Rivière Fond Gras and Rivière Blanche, northeastward-flowing tributaries of Rivière Carnot, northwest of Maïssade. Jones did not recognize the relations of the beds designated by him Maïssade "beds" to his Thomonde "beds." Woodring discovered that the Maïssade was a lignitiferous and very fossiliferous tongue of strata which projects into the body of the Thomonde formation. Because it is so richly fossiliferous, the Maïssade tongue is of much importance in the correlation of the Haitian Miocene.

Cercado formation.—C. J. Maury: Science, new series, volume 50, 1919, page 591; C. W. Cooke: Geological reconnaissance of the Dominican Republic, page 67 et seq.; T. W. Vaughan and W. P. Woodring: Ibid., pages 96, 97, 114 et seq.

From Cercado de Mao, a village on Rio Mao, Province of Santiago, Dominican Republic. Type locality, two bluffs on Rio Mao. One is just above Paso del Perro, which is about 5.5 kilometers by road upstream from Cercado de Mao, and the other is about 1.5 kilometers downstream, measured along the stream, from Paso del Perro. The approximate position of these two bluffs

is shown on the sketch map, plate 9, of the Geological Reconnaissance of the Dominican Republic. They are marked bluffs 2 and 3 of Maury. Unfortunately, the Cercado formation is not exposed at Cercado de Mao. The Cercado formation is the next important Miocene formation younger than the Baitoa formation in the Dominican Republic. It overlies a conglomerate, designated the Bulla conglomerate, which is correlated with the Baitoa. The Baitoa formation is very fossiliferous. Nineteen species of corals and about 500 species of mollusks, most of them studied by Maury, have been recognized. There are many Foraminifera and decapod Crustacea. The entire fauna is summarized by Vaughan and Woodring, op. sup. cit. The age of the Cercado is apparently upper Langhian.

Las Cahobas formation.—W. F. Jones: Journal of Geology, volume 26, 1918, page 737 et seq.; W. P. Woodring and J. S. Brown: Geology of the Republic of Haiti, 1924, page 196 et seq.

From the town of Las Cahobas, in the Central Plain of Haiti. The type locality lies to the north of the town. The Las Cahobas formation conformably overlies the Thomonde formation; it is the youngest Miocene formation in the Central Plain of Haiti and is the most extensive surface formation in the southeastern part of the Central Plain. It is moderately fossiliferous, containing Foraminifera, corals, and mollusks. According to Woodring, it is the equivalent of the Cercado formation of the Dominican Republic and is apparently of upper Langhian (Burdigalian) age.

Gurabo formation.—C. J. Maury: Op. et loc. sup. cit.; C. W. Cooke: Op. sup. cit., page 69 et seq.; T. W. Vaughan and W. P. Woodring: Op. sup. cit., pages 98 et seq. and 130 et seq.

From Rio Gurabo, Province of Santiago, Dominican Republic. Type locality, crossing over Rio Gurabo on road from Los Quemados to Gurabo Adentro, about three kilometers west of Los Quemados. For sketch map of this crossing, see Geological Reconnaissance of the Dominican Republic, plate 10. The Cercado formation passes under the Gurabo formation a short distance above the crossing over Rio Mao at Cercado de Mao. The fauna of the Gurabo formation is rich, but not so rich as that of the Cercado. It contains Foraminifera, corals, Bryozoa, and mollusks; there are between 70 and 80 species of corals and about 400 species of mollusks. Vaughan and Woodring (op. sup. cit.) have completely summarized present knowledge of the fauna, which seems to be of Helvetian age.

Mao Adentro limestone.—C. W. Cooke: Bulletin of the Geological Society of America, volume 31, 1920, page 219; and Geological reconnaissance of the Dominican Republic, 1921, page 73 et seq.; T. W. Vaughan and W. P. Woodring: Op. sup. cit., pages 100, 101, 151 et seq.

From Mao Adentro, a village on Rio Mao; for position, see plate 9 of Geological reconnaissance of the Dominican Republic. Type locality, bluff on Rio Mao, opposite Mao Adentro. The Mao Adentro limestone is a coralliferous limestone which immediately overlies the Gurabo formation. About 45 species of corals and 19 species of mollusks were collected in the formation. The fauna is very similar to that of the Gurabo formation, and therefore may be considered as of Middle Miocene, Helvetian, age.

Mao clay.—C. W. Cooke: Op. sup. cit., 1920, page 219; and op. sup. cit., 1921, pages 74, 75; T. W. Vaughan and W. P. Woodring: Op. sup. cit., pages 101, 153.

From the town of Mao, the old name for Valverde, on Rio Mao, Province of Santiago, Dominican Republic. Type locality, a bluff 2 or 3 kilometers south of Valverde, on the west, left, bank of Rio Mao; for position, see plate 9 of Geological Reconnaissance of the Dominican Republic. The Mao clay overlies the Mao Adentro limestone and is the uppermost Miocene recognized in the valley of the Rio Yaque del Norte. The fossil fauna is small, only one species of coral and nine species of mollusks having been collected in it, and these show no significant difference from the fauna of the Gurabo formation. The Gurabo formation, the Mao Adentro limestone, and the Mao clay are all apparently the correlatives of one European Miocene stage, the Helvetian.

Bowden formation.—W. H. Dall: United States Geological Survey, Eighteenth Annual Report, part 2, 1898, page 340; and Wagner Free Institution of Sciences Transactions, volume 3, part 6, 1903, page 1580 et seq.; R. T. Hill: Museum of Comparative Zoology Bulletin, volume 34, 1899, pages 82 et seq. and 145 et seq.; W. P. Woodring: Johns Hopkins University Circular, new series, 1917, page 242 et seq.; T. W. Vaughan and W. P. Woodring: Geological Reconnaissance of the Dominican Republic, 1921, page 100.

From Bowden, on Morant Bay, southeastern Jamaica. Type locality at Bowden. The shell and foraminiferal marl at Bowden is famous for the rich marine fauna it contains. Foraminifera, corals, and Bryozoa are well represented and of mollusks there are about 600 species. Woodring has in press, at the Carnegie Institution of Washington, a monographic account of the molluscan fauna. The Bowden horizon is fortunately one that can be recognized at many places in the Caribbean region. It is actually or very nearly the equivalent of the Gurabo formation of the Dominican Republic, and it is correlated by Vaughan and Woodring, 1921, with the European Helvetian Miocene.

Cerros de Sal formation.—C. W. Cooke: Bulletin of the Geological Society of America, volume 31, 1920, page 219; and Geological reconnaissance of the Dominican Republic, page 75; T. W. Vaughan and W. P. Woodring: Ibid., pages 103, 163, 164; D. D. Condit and C. P. Ross: Ibid., pages 201, 215.

From Cerros de Sal, a small range of hills which lies a short distance west of Laguna del Rincón, in the southwestern part of the Dominican Republic. Type locality, three kilometers west of the town of Las Salinas. The Cerros de Sal formation consists largely of gypsum and salt-bearing beds. It is moderately fossiliferous, 12 species of corals and over 70 species of mollusks having been obtained from it by Condit and Ross. The horizon is late Miocene, different from any other known Antillean Miocene formation. Although no positive correlation with European Miocene can be made, the age of the formation is probably Sarmatian or Pontian.

PLIOCENE

General statement.—Although a considerable number of stratigraphic designations have been applied to deposits of known or probably Pliocene age in

the Atlantic and Gulf Coastal Plain and in the Caribbean region, the paleontologic characterization of very few of the formations is sufficient to render the formations suitable for use as standards in geologic correlation. For this reason only three names for the Pliocene deserve consideration in the present connection. They are the Waccamaw marl of the Carolinas, the Caloosahatchee marl of Florida, and the Citronelle formation of the eastern Gulf Coastal Plain. The stratigraphic relations of the Pliocene at Limón, Costa Rica, are not known, and there is only slight, almost no, known development of fossiliferous Pliocene deposits in the Antilles.

Waccamaw marl.—W. H. Dall: Wagner Free Institution of Sciences Transactions, volume 3, part 2, 1892, pages 209, 210 et seq.; and United States Geological Survey, Eighteenth Annual Report, part 2, page 337; B. L. Miller: North Carolina Geological and Economic Survey, volume 3, 1912, page 250 et seq.

From Waccamaw River, Horry County, South Carolina. Type locality, not specifically designated. There are three localities. The first is Harpers Landing; later on, the property of Mr. William Nixon, about 15 miles by river and about 7.5 miles in a straight line upstream from Conway. The second is Nixonville or Grahamville, near which is Tillys Lake, a tributary of the Waccamaw. This locality is about three miles upstream from the first. The third locality, Todds Ferry, is about 12 miles from Conway by land and nearly three times as far by the river. All three localities are relatively close together, on Waccamaw River, upstream, in a general southeastward or eastward direction from Conway. The fauna is large, consisting of Foraminifera, corals, Bryozoa, and mollusks. Dall lists 180 species of mollusks.

Caloosahatchee marl.—W. H. Dall: Op. sup. cit., 1892, page 209; op. sup. cit., 1898, page 337; and Wagner Free Institution of Sciences Transactions, volume 3, part 6, 1903, page 1603 et seq.; G. C. Matson and F. G. Clapp: Florida Geological Survey, Second Annual Report, 1910, page 123 et seq.; G. C. Matson: United States Geological Survey Water Supply Paper 319, page 134 et seq.; T. W. Vaughan: United States National Museum Bulletin 103, pages 222, 223, 576.

From Caloosahatchee River, Lee County, Florida. Type locality, exposures along the river between Labelle and Olga. The fauna of the Caloosahatchee marl is very rich, at present known to contain 33 species of Foraminifera, 19 species of corals, 24 species of Bryozoa, and considerably over 600 species of mollusks. Over 700 species of marine invertebrates are known from the formation.

Citronelle formation.—G. C. Matson: United States Geological Survey Professional Paper 98, 1916, page 167 et seq.; E. W. Berry: Ibid., page 193 et seq.

From Citronelle, a town on the Mobile and Ohio Railroad, in the northern part of Mobile County, Alabama. Type locality, exposures along the railroad from Citronelle through a distance of three or four miles northward from the town. The Citronelle formation is non-marine, and it contains a small flora which has been described by Berry.

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CORRELATION OF THE TERTIARY FORMATIONS OF THE GREAT PLAINS[1]

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INTRODUCTION

The following discussion is intended to present the currently accepted correlation of the standard succession of western Tertiary mammal horizons, with an attempt to distinguish between its fixed and well proven features and those which are in varying degree doubtful or provisional, or in which recent evidence appears to indicate certain modifications. It is hoped that this method of presentation may be of aid in reconciling the evidence of the vertebrate faunæ with that of marine invertebrates and plants. It is also necessary to discuss the criteria used in making correlations, as a probable source of serious discrepancies lies in the methods of comparison, necessarily based on certain underlying assumptions which may not always be even approximately true.

[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formations of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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Summary of Criteria in Correlation

1. Direct superposition (in beds not overturned) is the fundamental evidence.

2. Stratigraphic continuity of lithologically similar strata or sequences of strata is usually, but not always, evidence of identical age. A certain type or sequence of deposits may shift progressively from one area into another, the shift covering a considerable lapse of geologic time. Instance, the eastward shifting of the Brule from Oligocene to Miocene.

3. Correspondent relations to widespread tectonic movements, and other geologic evidence, are important in many cases. Instance, the nearly simultaneous initiation of Oligocene sedimentation eastward of the Rockies from Montana to Colorado.

4. Faunal identity and relationships are the usual grounds for correlation of strata. This is necessarily the chief basis of comparison over wide areas and discontinuous formations, but its application is conditioned in various ways.

a. The faunas must be adequate and the identifications reliable. This is wholly a matter of degree, affected by the completeness of the specimens, their number, by more or less clearly diagnostic characters observable, by the judgment and experience of the identifier.

b. Certain genera and species appear to have wide geographic and limited geologic range and are of peculiar value in correlation. Of others the converse is true and they may have little or no value in this connection.

c. While identities in fauna point usually to correspondence in age, differences may be due to different facies in the fauna, varying conditions of sedimentation and preservation, geographic range, or to mere accidents of collecting, rather than to any difference in geologic age. Usually they are due to a combination of these factors, whose relative weight must be estimated.

d. The first appearance and the extinction of certain races or groups is very commonly used for correlation, but again must be used with judgment, its value turning largely on the apparent suddenness of their invasion or disappearance over wide areas, the adequacy of the faunal evidence, etcetera.

e. Probably the soundest evidence is that derived from the progressive structural modification of races or phyla of which a reasonably complete or adequate record is to be had.

It is rarely possible to use with vertebrate faunas the percentage methods of correlation commonly used in comparing marine invertebrates

and plant associations. This is partly because there is seldom any uniform facies among the faunas compared, partly because the correlation value of the different species of the fauna varies widely, the certainty and exactness of their identification varies equally widely, and the history of a fauna in any one region is rarely, if ever, that which is implicit in the percentage method of correlation, namely, the gradual and uniform replacement, one after another, of older by newer species or genera. How far this method applies to invertebrate marine faunas and to continental floras as a sound and accurate measure of their time relations I do not pretend to judge, but with fossil vertebrates one must depend on other criteria, as indicated above.

Value in Correlation of the Equidæ and other Phyla

In the American Tertiary formations the successive evolutionary stages of Equidæ are the most reliable guide fossils, for several reasons.

1. Abundance, especially in the later Tertiaries, but they have been found in every fauna of any importance.

2. Comparative unity of the phylum. There are few side branches, and those do not cause serious difficulty; in the main it is a direct, continuous, progressive series.

3. Progressive complexity of the molars to a highly characteristic pattern, so that single teeth can be readily recognized and exactly placed. Corresponding characteristic progressive specialization in the feet makes the foot bones also unusually diagnostic, although not so exactly so as the teeth.

4. The wide geographic dispersal of the Equidæ makes them of great value also in intercontinental correlations.

For these reasons it is well to take the Equidæ as our standard for correlation of American Tertiary land faunas and to confirm the series that they provide by the evidence of the evolution of other groups, the appearance and extinction of certain phyla and other pertinent data.

The Camelidæ, Cervidæ and Oreodontidæ, the rhinoceroses, the Proboscidea, Canidæ, Felidæ, and other carnivora afford more or less weighty evidence along this line. Other phyla are too incompletely recorded to depend much on them except at certain points. None of the lines cited, however, compares in value with the horses. In camels the teeth are relatively simple and do not undergo any such wide changes in specialization; the line is also complicated by a number of closely related side branches difficult to distinguish. The Oreodontidæ are only slightly better as to complication of teeth and are confused by numerous side

branches of varying progressiveness. The Cervidæ are no better and are relatively scarce. The rhinoceroses change only a little in tooth pattern and likewise fall into a number of subphyla of varying progressiveness. The Canidæ afford some evidence of value, but it takes a very special study of the group to make any safe use of them in correlation. The Proboscidea have considerable value, but partly because of their late appearance in the American Tertiary, partly because of their complex and much disputed phylogeny, they are difficult to handle. As invading types, certain genera are very helpful.

Critical Notes on Correlation Table

The standard succession of formations and faunæ is in the Central Great Plains and in the Tertiary basins of the Rocky Mountain region, where the order of their succession is determined by direct superposition. The succession is not all in one locality, but a number of overlapping sequences in different areas, as has been fully set forth by Osborn, in Bulletin 361, United States Geological Survey, and elsewhere. Taking the stages in the evolution of the Equidæ as our basis, the sequence of faunæ may be divided into nine primary zones, as shown in the accompanying table. The older Paleocene faunas, preceding the first appearance of the Equidæ, may also be divided into two primary zones, using the Multituberculates as standard; but in this case we are not using stages of a direct phyletic succession, merely characteristic genera. The Multituberculates in the Mesozoic mammal faunas, like the Equidæ in the Tertiary, have special advantages as a standard group for correlation, but their true phylogeny has not yet been worked out, as more material is needed to demonstrate it. Various guesses have, of course, been made.

Certain of these zones can be further divided into two or three phases with distinct and readily recognizable faunas. Beyond that I do not think it safe to go. It would be easy to suggest more minute subdivisions, but until our materials are more extensive and more adequately and critically studied, they can hardly be said to be demonstrated.

The *Equus* zone has been quite elaborately divided and correlated with Pleistocene glaciations by Osborn and Hay, but I regard all these correlations as tentative and resting largely on doubtful or inadequate evidence. As instance, the position and unity of the Aftonian is distinctly doubtful and the correlation of the Sheridan as its exact equivalent is also questionable. Yet it is on these and other very shaky foundations that the entire superstructure of the Pleistocene correlation rests. The equally elaborate correlation of European Pleistocene faunas appears

CORRELATION TABLE OF PRINCIPAL MAMMAL HORIZONS

Epochal correlations			Faunal zones	Typical	Formations
...orn, 1909	Merriam, 1918	Matthew, 1923 (tentative)		Plains and Rocky Mountains	Pacific Coast
...istocene	Pleistocene	Pleistocene	*Equus*		La Brea
		Pliocene		Sheridan	
...cene	Pliocene		*Hipparion*	Blanco	Eden
					Thousand Creek
				Republican	Rattlesnake
				Valentine	Ricardo
...cene		Miocene	*Merychippus*		Barstow
					Virgin Valley
				Pawnee	Mascall
	Miocene			Sheep Creek	Phillips Ranch
			Parahippus	Upper Harrison Lower Harrison	
		Oligocene			John Day
...gocene	Oligocene		*Miohippus*	*Leptauchenia*	
			Mesohippus	*Oreodon* beds *Titanotherium* beds	
		Eocene	*Epihippus*	Upper Uinta { Upper Washakie { Lower Uinta	
			Orohippus	{ Upper Bridger { Lower Washakie Lower Bridger	
...cene	Eocene		*Eohippus*	{ Upper Wasatch { Wind River Lower Wasatch	
		Paleocene	*Ptilodus*	Tiffany Torrejon	
			Tæniolabis	Puerco	

likewise to have far outrun the evidence. That there are differences between the earlier and later "Pleistocene" faunas is adequately proven, but that is about all as yet.

The *Hipparion* zone is in an equally unsatisfactory state as to its subdivisions. The differences are obvious enough between its earlier and later stages, and the extensive collections and thorough studies of the faunas now in progress by Mr. Childs Frick will probably lead to definite, clean-cut and adequately proven faunal divisions.

The *Merychippus* zone is quite definitely divided at the Snake Creek quarries into two distinct phases, and a third later phase appears to be typically represented by the Barstow fauna of California.

The *Parahippus* zone is definitely divided into two distinct phases (*Merycochœrus* and *Promerycochœrus* phases), but the evidence rests primarily on other phyla than Equidæ.

The *Miohippus* zone of the plains has not been divided, and it is open to some question whether it should be so broadly distinguished from the *Mesohippus* zone. It is, however, very imperfectly studied, the richer faunal zones above it and below it having absorbed most of the collecting.

The *Mesohippus* zone is divided into two well known phases (*Oreodon* and *Titanotherium* beds, = Brule (in part) and Chadron). It is probable that a third lower phase will be added when certain formations now included in the typical "*Titanotherium* beds" are more carefully studied. These are the Pipestone Creek and other deposits in Montana and supposed Chadron beds near Bates Hole and westward to Beaver divide, Wyoming.

The *Epihippus* and *Orohippus* zones are each definitely divided into two phases. The *Eohippus* zone includes two quite distinct phases at top and bottom, but these are connected by two intermediate phases completely transitional in fauna as well as stratigraphically.

The *Ptilodus* zone includes two distinct phases (Torrejon and Tiffany); the *Tæniolabis* zone (Puerco) is not yet subdivisible by the standards outlined above.

It is, perhaps, necessary to note that different collecting layers in the Torrejon and Puerco, as in later formations, show certain differences in *facies*, some genera being absent or rare in one layer, present or abundant in another; but in these cases the types or phyla that are common to the two levels all run through unchanged, indicating that there is no great time-space between them. The differences observed indicate merely that certain species were locally abundant when the one layer was deposited, rare or absent when the other layer was laid down, or not always even that. On the other hand, every phylum that passes through from Puerco

to Torrejon undergoes a change in species, nearly all a change in genus, while between Torrejon and Tiffany the continuing phyla are represented by different species in all instances where the material is abundant or adequate to show such small progressive stages. This kind of difference in fauna, when proved by a sufficient number of specimens in a number of continuing phyla, is what I have found in comparing the faunal zones or phases regarded as distinct in the present correlation.

Characteristic Genera of American mammal Faunas[2]

Zone	
Equus.....	Equus, Camelops, Elephas, Arctotherium, *Canis*, *Smilodon*, *Antilocapra*, *Bison*, *Mylodon*, *Glyptodon*, *Megatherium*, Platygonus, Megalonyx, Mammut.
Hipparion.....	Hipparion, Pliohippus, Protohippus, Procamelus, Megatylopus, Stegomastodon, Ælurodon, *Megalonyx Glyptotherium*, *Mammut*, Hypohippus, Merycodus, Blastomeryx, Alticamelus, Trilophodon, Teleoceras, Aphelops, Tephrocyon.
Merychippus...	Merychippus, Dromomeryx, Pronomotherium, Amphicyon, *Hypohippus*, *Merycodus*, *Protolabis*, *Alticamelus*, *Trilophodon*, *Teleoceras*, *Aphelops*, *Tephrocyon*, Parahippus, Blastomeryx, Merychyus, Merycochœrus, Promerycochœrus.
Parahippus.....	Diceratherium, *Parahippus*, *Kalobatippus*, *Blastomeryx*, *Oxydactylus*, *Ticholeptus*, *Promerycochœrus*, *Merycochœrus*, *Merychyus*, *Moropus*, Miohippus, Entelodon, Ancodon, Cynodesmus, Nothocyon, Temnocyon, Enhydrocyon, etc.
Miohippus.....	Eporeodon, Protoceras, *Miohippus*, *Leptauchenia*, Mesohippus, Cænopus, Hypertragulus, Leptomeryx, Agriochœrus, Entelodon, Ancodon.
Mesohippus....	Hyracodon, Metamynodon, Oreodon, Poëbrotherium, Hypisodus, Leptochœrus, *Mesohippus*, *Cænopus*, *Agriochœrus*, *Leptomeryx*, *Hypertragulus*, *Daphœnus*, "*Cynodictis*," *Dinictis*, *Hoplophoneus*, *Entelodon*, *Ancodon*, *Ischyromys*.
Epihippus.....	Epihippus, Amynodon, Diplacodon, Protitanotherium, Eobasileus, Protylopus, Protoreodon, Oxyænodon, Prodaphænus, Paramys, Harpagolestes.
Orohippus.....	Orohippus, Palæosyops, Uintatherium, Helohyus, Homacodon, Tillotherium, *Hyrachyus*, *Mesonyx*, Paramys, Vulpavus, Miacis, Patriofelis, Limnocyon, Sinopa, Notharctus.

[2] First appearance in italics; small capitals indicate that the genus is limited to the zone.

Eohippus..... EOHIPPUS, SYSTEMODON, HEPTODON, CORYPHODON, DIACODEXIS, PELYCODUS, DIDYMICTIS, OXYÆNA, PALÆONICTIS, PACHYÆNA, *Hyopsodus*, *Paramys*, *Sinpa*, Phenacodus.

Ptilodus..... PTILODUS, TETRACLÆNODON, CLÆNODON, DISSACUS, HAPLOCONUS, CONORYCTES, PSITTACOTHERIUM, CHRIACUS, DELTATHERIUM, MIXODECTES, *Phenacodus* (top only), Periptychus, Mioclænus, Anisonchus.

Polymastodon.. POLYMASTODON, ECTOCONUS, CONACODON, TRIISODON, ONYCHODECTES, WORTMANIA, LOXOLOPHUS, *Anisonchus*, *Mioclænus*, *Periptychus*.

THE EOCENE SEQUENCES OF THE MOUNTAIN BASINS

Occurrence mainly in intermontane basins of the Rocky Mountain region from New Mexico to Montana and Alberta.

1. San Juan basin, Northwest New Mexico, Southwest Colorado
   - Wasatch
     - Fossiliferous zone = Middle Wasatch
     - Tiffany } ..... = Cernaysian (France)
     - Torrejon } = Fort Union
   - Puerco ? ? facies = Lance or later
   - Ojo Alamo gr. = Edmonton or later

2. Huerfano basin, Central Colorado
   - Upper Huerfano = Lower Bridger
   - Lower Huerfano = Lost Cabin

3. Uinta basin
   - Uinta (Browns Park) Upper / Lower = Upper Washakie
   - "Wasatch" ? = Lysite

4. Bridger basin
   - Upper Bridger = Lower Washakie
   - Lower Bridger
   - Green River (type locality)

5. Washakie basin
   - Upper Washakie
   - Lower Washakie
   - Wasatch

6. Wasatch (Evanston)
   - Knight = Lysite
   - Fowkes } nonfossiliferous
   - Almy }
   - ? Laramie

7. Wind River
   - Lost Cabin
   - Lysite

8. Bighorn basin

   Wasatch
   - Lost Cabin } = Wind River group
   - Lysite }
   - Gray Bull
   - Sand Coulee

   Fort Union
   - Clark Fork = Tiffany or slightly later
   - "Fort Union" No vertebrate fossils

9. Fort Union (Montana)	Upper part probably = Torrejon and Tiffany
10. Alberta	Paskapoo ? ? facies of Lance Edmonton Belly River = Judith River Two Medicine

The Eocene sequence as set forth by Osborn has been very thoroughly confirmed by study of the faunas since 1909. The doubtful points now are:

First, as to the relations of the Upper Uinta to the Oligocene. The only place that these are shown superposed is in Beaver divide, central Wyoming, where Granger secured a small Upper Eocene fauna and, in overlying beds, a small Lower Oligocene fauna. It is not yet demonstrated whether the Upper Uinta is separated by a time gap from the Lower White River (Chadron), or immediately precedes it, or is in part contemporaneous, but represents a widely different faunal facies.

Second, the relations of the Paleocene to the latest dinosaur beds and the dividing line between the Cretaceous and Tertiary. I stated the vertebrate evidence in 1914 and 1919. Since then discoveries in the New Mexican dinosaur beds and some further studies on the Fort Union tend to show that the Puerco is later than the Edmonton, probably equivalent to the Lance or later, and that the Fort Union is probably equivalent to Torrejon plus Tiffany, but there is nothing to show that any part of the Fort Union should be correlated with the Puerco.

The Great Plains Succession, Oligocene to Pleistocene

A great amount of collecting has been done in recent years and the faunal succession has been more fully demonstrated. Most of the faunal horizons distinguished in 1909 have been fully validated and one additional horizon has been added. The Pliocene succession, however, is still a doubtful problem. There are probably three or more successive faunas, but conclusive proof of their stratigraphic succession or of the distinctness of the faunas has not yet appeared.

The Pliocene as currently distinguished opens with the appearance of the more progressive group of three-toed horses—*Hipparion, Protohippus,* and *Pliohippus*—replacing *Merychippus* of the Miocene. This is a clean-cut distinction supported by several other faunal changes in different phyla. The earliest phase appears to be represented by the Valentine beds of Nebraska, Clarendon of Texas, Santa Fé of New Mexico, and Madison Valley beds of Montana. The Republican River and Upper Snake Creek of Kansas and Nebraska probably represent a later phase

of the Lower Pliocene, but have not been satisfactorily differentiated faunally. Both are currently placed as Lower Pliocene. The Blanco of Texas and a new fauna secured by Gidley in Arizona are undoubtedly later than these and are considered as Middle or Upper Pliocene; but, until more is known of later Pliocene faunas in Nebraska, Kansas, and Colorado, the correlation is provisional. The *Equus* beds of the Central Great Plains overlie these Lower Pliocene fossiliferous zones, with evidently a considerable gap, stratigraphic and faunal, between them. There are beds of intermediate age, but so poorly exposed and so scantily fossiliferous that we do not know their exact faunal characters.

Whether the *Equus* beds of western Nebraska and Kansas are at the base of the Pleistocene or the top of the Pliocene is another point that has not been conclusively settled. It turns largely on their real relations to the earliest glacial advances. Their supposed correlation with the Aftonian of Iowa is by no means finally proved, nor are the relations of the Aftonian beyond dispute.

This whole problem of the Pliocene succession calls for extensive field-work and collecting. It is not to be settled in the office. But I do not think the time is ripe to undertake such a study until the underlying Oligocene and Miocene formations have been more accurately correlated and collections made and competently identified from their eastward and southward extensions.

The Pacific Coast mammal Faunas

The oldest of these is the John Day, which I regard as essentially a unit, although the occurrence of *Promerycochœrus* only in the upper part seems to divide it. There is very little else to separate the Upper John Day, so far as has yet been shown, and both the upper and lower faunæ are very largely identical with that of the Lower Rosebud, with the important exceptions that *Parahippus* is not found and that *Promerycochœrus* occurs only in the upper levels. For these reasons one may consider the John Day as slightly older than the Rosebud, but decidedly later than the Upper White River (*Protoceras* beds). I do not think there is any adequate reason to place it in a separate intermediate division, but would rather class it with Lower Rosebud.

The Mascall appears to be a near equivalent to the Pawnee Creek, Lower Snake Creek, and Deep River, but again slightly older. I do not see any reason to place it in a separate division, as it is closely related to these and decidedly later than the Sheep Creek faunal phase. The Rattlesnake of the John Day basin appears to be nearly equivalent to the Republican River.

The Virgin Valley beds appear to be a near equivalent to the Pawnee Creek.

The Barstow in the Mojave basin appears to be distinctly later in phase than the Pawnee Creek and may be allowed as a separate division between it and the *Hipparion* zone. The Ricardo in the same basin appears to be equivalent to the Valentine or Republican River, but the position is not well defined. The Thousand Creek in Nevada is considered as probably later than Republican River, but earlier than Blanco. It may fill the faunal gap between them or may be associated with the Republican River. The San Timoteo fauna in the Eden neighborhood is perhaps equivalent or later, but its final correlation will turn on the large collections secured by Mr. Frick, which have not yet been completely studied.

European Equivalents

As we are using a time-scale of world-wide application, based on the sequence of formations and faunas and floras of western Europe, I do not see that it is possible to avoid using these faunas and floras as our standard of correlation. It may not fit well the sequence of geologic events in America, but it is obviously necessary that the Miocene epoch of geologic time should begin and end at the same time all over the world, even if the division must be run through the middle of a formation in this country This is awkward for the geological mapmakers, but it can not be helped.

European geologists, however, are by no means agreed in all particulars as to their time-scale and correlations and there are many disputed correlations of terrestrial faunas. In making disputable American correlations with European faunas whose exact position is in question, there is room for considerable difference of opinion and it is well to avoid dogmatism.

Osborn's correlation of the Western Tertiary faunas, as published in 1909 (U. S. Geological Survey Bulletin 361), is generally accepted as standard for vertebrate work. Without attempting to discuss the whole of this correlation, I will consider certain modifications that have been proposed and the bearing of some new evidence.

1. Osborn, Merriam, and Matthew have agreed on one change of some importance, the transfer of the entire *Hipparion* zone to the Pliocene. The greater part of it had been regarded by Osborn as Upper Miocene. A restudy compels me to return to Osborn's correlation of 1909 (following the earlier views of Cope), on the following grounds:

The Pontian fauna of Eurasia, including the Pikermi and Samos

faunas and the Middle Siwalik fauna of India, is placed by some authors at the top of the Miocene, by others at the base of the Pliocene. *Hipparion* appears in this fauna as an invading type, apparently from America, and the species are larger and more specialized than most of the American *Hipparions*. In America *Hipparion* is an autochthonic type; the species are small and primitive in the lower part of the *Hipparion* zone; some of them distinguished with great difficulty from the *Merychippi* of the preceding faunas. These progressive Old World *Hipparions* appear first at the base of the true Siwalik beds,[3] correlated with the Tortonian. It would appear, therefore, that the entire lower part of the American *Hipparion* zone can not be later than the Tortonian. The Equidæ evidence is supported by other phyla, which I will not take time to discuss here. The conclusion would be that all of the so-called Lower Pliocene will have to be set back to Upper Miocene, leaving in the Pliocene only the Blanco, Eden, and other later faunas.

2. It has been customary to regard the appearance of *Equus* and the earliest traces of glaciation as the base of the Pleistocene. This it may also be necessary to reconsider. *Equus* is quite characteristic of the Upper Pliocene of Europe, apparently also of India, and some rather obscure evidence from Mongolia indicates its association there with *Hipparion* in a formation which, on its physiographic geology, would seem to belong in the Pliocene. If geologists will agree that the earliest glaciation in the Rocky Mountain region may have synchronized in time with the Upper Pliocene of Europe, it may be advisable to transfer a part of the *Equus* zone to Upper Pliocene.

It will be recalled that Cope was disposed to refer the "*Equus* beds" to the Pliocene, and that their later allocation to the Pleistocene was based largely on arguments in connection with Gilbert's studies of Lake Lahontan. Reconsidered in light of our present knowledge, these arguments appear to me somewhat unconvincing.

3. The discovery in Mongolia and in Burma of Titanotheres equivalent in stage to those of the Upper Uinta throws an important light on correlation. In Burma the Pondaung series is overlain by the marine Yaw formation, correlated by its nummulites and mollusks as Upper Eocene. The Pondaung titanotheres are certainly not older than those of the Upper Uinta and the formation is most likely Bartonian—that is, in the lower part of the Upper Eocene. This would set back the Uinta to the Middle or early Upper Eocene.

[3] Pilgrim says at the base of the Upper Chinji, but Brown's Siwalik collections show that *Hipparion* occurs through to the base of the Lower Chinji, although not common.

4. Teilhard's studies of French Eocene and Paleocene mammals tend to show the equivalence of the Sparnacian of Europe with the middle or upper part of our Wasatch rather than with the lower, and of the Cernaysian of Europe with the Tiffany faunal zone at the base of our Wasatch, not with the underlying Torrejon, with which it has heretofore been correlated.

5. I have made some tentative suggestions of correlation of the Puerco, the earliest of our mammal faunæ, with the Lance, the latest of the dinosaur faunæ, instead of putting it later than the extinction of the dinosaurs, as has heretofore been universally accepted.

It will be observed that all of this evidence tends to set back the American succession of vertebrate faunas to somewhat older European equivalents than the correlations generally accepted. The *Equus* zone may be in part Upper Pliocene; the *Hipparion* zone in part Miocene; the lower part of the *Parahippus* zone would fall into the Oligocene; the lower part of the Chadron or *Titanotherium* beds may be Upper Eocene; the Tiffany beds at the base of the Wasatch will be Paleocene, and the Puerco may be considered as uppermost Cretaceous by those who would draw the line between Cretaceous and Tertiary at the extinction of the dinosaurs.

These possible modifications indicated by the newer vertebrate evidence are frankly provisional suggestions of my own. I have not as yet discussed them fully with my confrères nor published the arguments on which they rest. I have no desire to pose as representing vertebrate paleontology, or even as representing the American Museum, but only to call attention of my invertebrate and plant-loving friends to the doubtful points in our evidence and the possible bearing of some of our recent discoveries and researches on the generally accepted correlation of our Tertiary land faunas. If these serve to reconcile some of the discrepancies with the correlation of marine faunas and of the plant-bearing beds, we shall be so much nearer to reconciling the evidence. If they increase the discrepancies, it will be in order to study the evidence more carefully from both ends and find out what is the matter with its interpretation.

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TERTIARY PELAGIC MAMMALS OF EASTERN NORTH AMERICA[1]

BY REMINGTON KELLOGG

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INTRODUCTION

It seems desirable to open this subject with a brief discussion of the present distribution of living pelagic mammals, for without this introduction the relative importance of the various types for intercontinental correlation might not be clearly understood.

All the living and fossil pelagic mammals now known may be referred to three larger groups—the Sirenia, the Carnivora, and the Cetacea. Of these the sirenians, or sea-cows, are probably the most retiring, the least aggressive, and more local in their distribution. The pinnipeds, which

[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formations of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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are pelagic carnivores and are generally known as seals, walruses, and sea-lions, congregate in colonies at favorable localities, and at least one member of this group, the fur seal, makes long periodic migrations from its summer breeding places to its winter feeding grounds. Another suborder of the Carnivora has had at least one pelagic type, the sea-otter. The range of this animal formerly included the coasts and islands of the North Pacific Ocean, and in North America extended from the kelp beds of Lower California northward to Bering Sea. The living Cetacea are usually divided into two main suborders—the whalebone whales and the toothed whales. These mammals are great travelers and spend their entire lives in the water. The possibilities for the dispersal of the cetaceans are exceptionally great, in view of the absence of physical barriers, and the chief controlling factor, apparently, is the food supply. Of the 28 genera of living toothed whales, 4 are restricted to large rivers and their estuaries. One or two genera, like *Sotalia* and *Steno*, are essentially tropical in their distribution; *Steno* strays as far north as Florida. The other genera of dolphins are more widely distributed, and some of them, especially the killer (*Orcinus*), the lesser killer (*Pseudorca*), the blackfish (*Globicephalus*), and the common dolphin (*Delphinus*), are practically cosmopolitan. The bowhead, which frequents the Arctic seas, appears to be the only one of the seven genera of living whalebone whales which is restricted in its dispersal by climatic conditions. Some of the living whalebone whales are without doubt the largest pelagic mammals that have ever lived. No marine mammal, not even the zeuglodonts, attained the proportions of the sulphur-bottom whale, individuals of which have measured 98 feet. Not all of the living whalebone whales are so large, and one of the smallest is the pigmy right whale, which sometimes reaches a length of 20 feet.

On tabulating the various occurrences of stranded and captured whales, it became obvious that the existing cetacean faunas of European and North American waters, with the exception of the pigmy sperm whale, are, as a whole, homogeneous, in so far as genera are concerned. As regards species, there are some exceptions. On passing from the existing fauna to that of the Tertiary, we are confronted at once with the present inadequacy of the pelagic faunas for certain critical stages.

Eocene

Middle Eocene pelagic mammals of the Fayum, Egypt

So far as I am aware, no pelagic mammals have been found in the Lower Eocene, unless a form from Nigeria recently described by Andrews

as *Pappocetus* belongs to that period. The allocation of the incisor-like tooth from the Shark River marl pits of New Jersey, which Cope called *Hemicaulodon effodiens,* is too uncertain at present for any discussion of its possible relationships. Cetaceans and sirenians, however, are present in beds referable to the lower Middle Eocene. The most primitive cetaceans and the oldest sirenians of which we have any knowledge were well specialized for a pelagic life. These old cetaceans have been called zeuglodonts, in allusion to the yokelike appearance of the cheek teeth. A somewhat generalized zeuglodont, *Protocetus atavus,* from the basal member of the Lower Mokattam stage of the Fayum, Egypt, has been described by Professor Fraas. The skull of this small zeuglodont is less than two feet in length and bears little resemblance to living cetaceans. In common with the oldest land mammals, there is a marked difference between the anterior cheek teeth, or premolars, and the posterior cheek teeth, or molars. In contrast to zeuglodonts in later stages, the teeth of *Protocetus* do not bear steplike cusps on their anterior or posterior margins. Leriche in 1921 referred the Lower Mokattam to the Lutetian.

UPPER EOCENE PELAGIC MAMMALS OF EGYPT, ALABAMA, AND SOUTH CAROLINA

By the end of the Middle Eocene true zeuglodonts had made their appearance, and their remains have been found in later Eocene formations in Russia, Poland, Germany, and North America. A large zeuglodont, *Zeuglodon isis,* with long vertebræ, which makes the nearest approach to our North American form in size, is first known in the Wadi-Rayan stage of the Fayum and is likewise present in the succeeding Ravine and Birket-el-Qurun stages. The skull of this form is slightly more than 3½ feet in length and the cheek teeth have cusps on their anterior and posterior cutting edges. Three other zeuglodonts were associated with this large form in the Birket-el-Qurun stage of the Upper Eocene. The small zeuglodont, *Zeuglodon osiris,* was about 10 feet long, and the length of the skull equaled one-fourth or one-fifth of the total length of the skeleton. The condition of the olfactory apparatus indicates that the sense of smell was retained by these early zeuglodonts, and Dart, from his study of brain casts, has brought forth evidence to show that the sense of touch was highly developed in the muzzle. This tactile specialization no doubt influenced Stromer (1906) and Andrews (1907) to some extent when they advanced their theory that zeuglodonts were restricted to shorelines and were used by them to indicate the location of shorelines of former land connections between the Old and New Worlds. As the tail vertebræ of these zeuglodonts are very large and the skeleton,

as a whole, rather slender, the conclusion can be drawn that these animals propelled themselves through the water by upward and downward strokes of the flukes, after the manner of living whales.

At least three zeuglodonts were present in the Eocene seas which covered the Gulf Coastal Plain during Jackson time. Two of these were large forms, one of which, *Zeuglodon cetoides,* attained a length of from 50 to 70 feet and its skull measured approximately five feet. This zeuglodont has long vertebræ, while the other large form had short vertebræ. In comparison with these large zeuglodonts, the third form, *Zygorhiza minor,* appears rather small, for its total length was not much more than 15 feet. The skull was about three feet long. The forearm of *Zygorhiza* was modified along the lines of the living cetacean type of pectoral fin, but the finger bones are long and slender and not flattened, as in the latter. The small zeuglodont of the Birket-el-Qurun and Qasr-el-Sagha stages of the Fayum in Egypt is even smaller than the Jackson *Zygorhiza,* for none of the skulls of *Zeuglodon osiris* which have been found exceed 28 inches in length.

To summarize the above, it may be said that the Upper Eocene stages of Egypt and the Jackson formation both possess at least three distinct types of zeuglodonts. In both localities there is a large form with long vertebræ, a large form with short vertebræ, and a small form with short vertebræ. The zeuglodonts of the Jackson are larger than those of the Fayum and differ in certain essential features which need not be discussed here.

It seems to be generally conceded that the gigantic forms mark the flood tide in the evolutionary advance of most groups of animals, after which the stock does not find conditions so favorable as previously for multiplication and dispersal. The Jackson fauna includes the largest zeuglodonts known to us at present.

There is another line of evidence which may be introduced at this point, and that is the occurrence of certain archaic types of toothed whales in the Cooper marl of South Carolina, which is correlated with the Jackson group. One of these, *Agorophius pygmæus,* has been known for at least 75 years (1847), and was obtained by Prof. F. S. Holmes in marl at Greer's Landing, on the Ashley River, about 10 miles from Charleston, South Carolina. A second type, *Xenorophus sloanii,* was found during the past year at Woodstock Station, in Berkeley County, South Carolina. A small zeuglodont, *Dorudon serratus,* was first discovered some 80 years ago (1845) in a marl pit worked by planters near the Santee Canal, South Carolina. No definite locality is known for the

other archaic toothed whale, *Archæodelphis patrius,* but the matrix and the Foraminifera which are contained in it seem to indicate that the specimen was derived from the Jackson formation of Alabama. The skulls of these small archaic toothed whales are constructed along somewhat different lines from those of the zeuglodonts and do not appear to be directly related to them. Their previous geological record is unknown to us at present. If they were contemporaneous with the Middle Eocene and earlier Upper Eocene zeuglodonts, it seems surprising that their remains have never been found or identified among the many specimens obtained by the various parties which have explored the Fayum. Another possibility to be taken into consideration is that these archaic toothed whales may have been developing in some other part of the world, and that they first came into association with the zeuglodonts on the shores of North America. If these archaic toothed whales of the Cooper marl were contemporaneous with the gigantic zeuglodonts of the Gulf Coastal Plain, and at present we have no direct evidence to the contrary, then it may be suggested that the Jackson represents a later stage than the Qasr-el-Sagha of the Fayum, which this year has been referred to the Bartonian by Andrews.

Oligocene Cetaceans, Sirenians, and Pinnipeds

Unfortunately, the known Oligocene pelagic mammals are represented by such scanty material and are of so rare occurrence that we are at loss to account for such an extraordinary condition. From the evidence available at present, the inference is drawn that the zeuglodonts apparently reached the climax of their evolutionary advance toward the close of the Eocene, and at the same time the archaic types of toothed whales make their appearance. A small number of pelagic mammals are known from the Middle Oligocene of Europe. Among these is the oldest known pinniped, *Palæotaria,* which comes from the coarse limestone near Rennes, France. A small shark-toothed whale, *Microcetus,* is known from the marl in the Osnabruck basin, near Bunde, in Germany. Two other imperfectly known cetaceans, which have been named *Pachycetus robustus* and *Pachycetus humilis,* were found many years ago (1883) in the phosphate deposits of Helmstedt, Germany. A sirenian, *Halitherium schinzi,* has been found in the deposits at Flonheim, Rhein-Hessen, and also near Paris and near Bordeaux. All of these forms have been assigned to the Rupelian stage and no new discoveries have been reported during the past forty years.

What solution can be offered for their apparent absence in the Upper and Lower Oligocene marine formations? A number of geologists who have devoted considerable time to the study of marine Oligocene formations on both the Atlantic and Pacific coasts of North America have remarked that they have never observed any remains of cetaceans in the course of their fieldwork. It may seem surprising that this group of pelagic mammals should dwindle in numbers to the point where their remains are so rare as to be almost negligible in comparison to those of the other periods; yet a wide variety of new types of cetaceans make their appearance in the Lower Miocene. It seems desirable that careful search should be made along the shorelines of the Oligocene seas for remains of pelagic mammals.

Miocene

Pelagic mammals from the Aquitanian white sands of Linz, Austria

Coming to the Miocene, we find a rather varied assemblage of cetaceans. The oldest known Miocene pelagic mammals, if they really belong to this period, occur in white sands in the vicinity of Linz, Austria. A Miocene survivor, *Patriocetus,* of the archaic toothed whales, which previously are known only from the Cooper marl, is present in these sands. The earliest known representative, *Cetotheriopsis,* of a family of small whalebone whales known as cetotheres, which have a wide distribution during the later Miocene, is also present. A third type of cetacean, *Agriocetus,* and a sirenian, *Halitherium christoli,* also occur there. No contemporaneous fauna is known at present.

Burdigalian faunas of pelagic mammals in Patagonia and Italy

In wide contrast to the Aquitanian fauna of archaic toothed whales, an entirely different assemblage of cetaceans appears in the Burdigalian. Some of the characteristic types of the later Miocene appear, and with them are associated certain peculiar forms whose ancestry, relationships, and geologic range are much disputed. Even in the skulls of these early Miocene dolphins, the nasal apertures have been pushed backward to the level of the eyes and the choanæ are nearly vertical—an adaptation for breathing in the water. The oldest known marine formation of this stage appears to be represented by the Patagonian tuff formation on the coast of Chubut Territory, Patagonia. This assemblage of pelagic mammals has some types in common with later marine formations of North America and elsewhere, and what is of more interest in the present con-

nection is the occurrence of types similar to those which have been described by Dal Piaz from the "arenaria" of Libano and Bolzano, near Belluno, in the department of Venetia, Italy.

Among the peculiar types of cetaceans found in the Patagonian formation is a small shark-toothed dolphin, *Prosqualodon australis.* Dolphins of this type have been called squalodonts because of the general similarity between their teeth and those of sharks; but the teeth of the squalodonts have two or three roots in contrast to those of sharks. The skull of *Prosqualodon* presents an example of what may be assumed to represent an early stage in the general trend of a process which has been called telescoping and which is so evident in later representatives of this group. The position of the parietal bones may be taken as the critical feature to illustrate this point. These parietal bones form the outside of the braincase and extend upward, meeting the opposite one at the vertex of the skull. In later forms there is a more evident telescoping of the skull in a fore-and-aft direction, and the parietal bones no longer reach the vertex. In addition to this squalodont, there is a peculiar dolphin, *Diochotichus,* which possesses so many anomalous features that some doubt still exists as to its relationships. Winge thought it was the most primitive form known of the beaked whales (family Ziphiidæ); others have considered it to be a squalodont with simple, single-rooted, conical teeth. More recently Dal Piaz made a new family for the reception of this dolphin and an allied genus, *Squalodelphis,* found in the Upper Burdigalian of Belluno, Italy. In addition to other peculiarities exhibited by this skull, there are two small apertures in the anterior wall of the braincase for the passage of sensory nerves to the mucous membranes of the nose. Similar foramina are present in the squalodonts and in the Miocene fossil dolphin *Ceterhinops longifrons* from the Ashley region of South Carolina. With the progress of the telescoping of the cetacean skull a small bone (mesethmoid), which forms the upper partition between the nasal passages, or blow-holes, expands laterally and closes these passages. The organs connected with the sense of smell degenerate and the apertures which afford passage to the corresponding nerves close. The sense of smell, apparently, does not have any particular utility in the welfare of the cetaceans, but the changes in the sensory apparatus are followed by correlated modifications in the mechanical construction of the skull and afford another check on the stage of evolution represented in the types now known. The basal Miocene genus, *Cetotheriopsis,* is also found in this formation. In addition, there is a long-beaked dolphin, *Argyrocetus;* a river dolphin, *Proinia,* and two other cetaceans which may represent sperm whales. One of these cetaceans, *Scaldicetus*

[*Physodon*], has a wide distribution in the later Miocene stages. The assemblage as a whole seems to bear out the assumption that these cetaceans are representatives of the older or Lower Burdigalian fauna.

The skull of the fossil dolphin *Argyrocetus,* from the Patagonian formation, represents the earliest known form with a narrow beak. The beak of this skull was about twice as long as the cranium and its width at the base about one-fifth of its length. In later Miocene the beaks of some of the porpoises become excessively elongated, but these dolphins disappear some time during the Pliocene. None are known from marine formations later than the Parana stage of South America. At least three genera with narrow beaks, *Eoplatanista, Cyrtodelphis,* and *Ziphiodelphis,* occur in the Belluno deposits in Italy. The squalodonts found in the vicinity of Belluno belong to the later Miocene types and are found in association with what appears to be a related form of the Patagonian dolphin, *Diochotichus,* as well as with other genera which have not been found thus far in later Miocene stages. Among these is a small shark-toothed microzeuglodont which is represented by the closely allied genera *Neosqualodon* and *Microsqualodon.* Remains of these dolphins have been found in a number of localities in Italy, but always in the Upper Burdigalian. What appear to be related genera are known from the Caucasus and from the Middle Oligocene of Germany. The sirenian *Halitherium* also appears for the last time in the Lower Burdigalian of Italy. Taken as a whole, the Belluno fauna is unquestionably older than any of the other European Burdigalian marine deposits which contain remains of cetaceans and represents a slightly later stage than the Patagonian of South America. Gemmellaro (1921) and others have assigned the deposit near Belluno to the Upper Langhian or Upper Burdigalian. Hence this is additional evidence for referring the Patagonian stage to the Lower Burdigalian.

HELVETIAN FAUNAS OF PELAGIC MAMMALS IN FRANCE

Dolphins with skulls which are characterized by long, narrow beaks become more plentiful, both in numbers and in species, during the Helvetian. Unfortunately, no effort seems to have been made in recent years to obtain additional specimens of some of these Helvetian dolphins and our present information is limited to the fragmentary specimens which have been known for more than a century and which were described by Cuvier. The characteristic dolphins of this stage have been referred to the genera *Schizodelphis, Pomatodelphis, Champsodelphis,* and *Stereodelphis.* Remains of these cetaceans have been found in the Rhone Valley in the departments of Drome and Herault, in the Loire Valley near

Angers, and near Dax, in the department of Landes, France. Squalodonts and sperm whales are also present in these deposits. *Mesocetus,* a later Miocene cetothere, is known for the first time from this stage. Helvetian representatives of the sirenian group have been described as *Prohalicore dubaleni* and *Metaxytherium cuvieri.*

TORTONIAN FAUNA OF PELAGIC MAMMALS IN MARYLAND

Since the Calvert formation is well represented by pelagic mammals, one is enabled to make comparisons with earlier and later Miocene faunas. Although additional material is needed to interpret convincingly the relations of certain forms, at least 22 cetaceans referable to six families are present. This assemblage includes squalodonts, sperm whales, dolphins (both longirostrine and brevirostrine), river dolphins, and cetotheres. In addition, one seal and one sirenian are known. One of the characteristic genera of this formation is the genus *Eurhinodelphis,* a dolphin with a very long beak. The absence of alveolæ for teeth on the distal one-third of beaks of these dolphins, in conjunction with other cranial peculiarities, readily distinguish this genus. Two, and possibly three, different dolphins of this genus were present in the Calvert formation, but none of them appear to be identical with those of the succeeding stage in the Antwerp basin. Other long-beaked dolphins in the Calvert formation are referable to the genera *Schizodelphis* and *Rhabdosteus.* At least three small short-beaked dolphins of the genus *Delphinodon* and a related genus are found in this formation, and these dolphins appear to have their closest counterparts in the genera *Pithanodelphis* and *Protophocæna* of the Antwerp basin in Belgium. Besides the above-mentioned genera, which are represented by closely related forms in both deposits, the Calvert formation of Maryland possesses one additional highly specialized dolphin. This dolphin was named *Zarhachis flagellator* by Cope and a nearly complete skeleton was collected by Norman Boss in the fall of 1921. The skull of this dolphin represents one of the extreme stages in the lengthening of the beak. This skull is nearly 4 feet long, and the beak is fully five times as long as the cranium. At the extremity the beak is about an inch wide and at the base approximately 6 inches, but it is only 3 inches thick at the base and less than half an inch at the extremity. *Zarhachis* undoubtedly must mark the culmination of the long-beaked type of dolphin with small braincase. Mechanical difficulties would interfere with a further development of this type of beak. From this it appears that *Zarhachis* may represent one of the end lines of the river dolphins.

No representatives of the true whalebone whales have been found thus far in the Calvert formation, but the cetotheres were represented by a number of types. At least two of the last-mentioned family are related somewhat closely to forms occurring in the Antwerp basin, and when further material is found it is possible that similar relations will be established for the other forms. The sirenian and the seal do not correspond to those present in the Antwerp basin.

By taking each form that is present in the Calvert formation and by making comparisons with those of the Anversian of Belgium, the Tortonian of Hungary, and the Sarmatian of Austria and southern Russia, the evidence seems to indicate that this Calvert fauna should be placed between the Helvetian stage of France and the Anversian of Belgium.

SARMATIAN FAUNA OF PELAGIC MAMMALS IN BELGIUM

The Anversian stage of the Antwerp basin, Belgium, is represented by the largest fauna of pelagic mammals thus far known for any one formation. When the fortifications of Antwerp were under construction, in the years 1861 to 1863, hundreds of whale skeletons were found in the excavations. Twenty-eight cetaceans, representing squalodonts, sperm whales, beaked whales, dolphins (both longirostrine and brevirostrine), cetotheres, and true whalebone whales, as well as one sirenian, and two seals comprise this fauna. True beaked whales of the family Ziphiidæ are represented by six forms. No occurrences are known for members of this family in earlier stages, with the possible exception of certain isolated teeth. The genus *Eurhinodelphis* is represented by three species. Dolphins of the genera *Schizodelphis* and *Acrodelphis* are also present. The two short-beaked dolphins have been mentioned previously. The squalodont resembles the Calvert form in certain respects, but there are differences. The widespread genus *Squalodon* is not known from deposits later than this stage. Judging from their sharklike teeth, these squalodonts were well adapted for a predaceous life, and hence could secure an adequate food supply wherever fish were present in sufficient numbers to insure easy capture. Unless the prevailing pelagic conditions were radically different during the Miocene than at present, their distribution should correspond in a general way with that of the living killer whale (*Orcinus*). All the squalodonts now known retained some sense of smell, if our interpretation of certain foramina in the fore part of the braincase is correct. Whether or not this affected their chances for survival can not be answered at present. As the squalodonts were rather widely distributed during the Miocene, the different species should be given considerable importance in correlation studies. Their remains

have been found in Europe, North America, South America, New Zealand, and Australia.

On the whole, the Anversian fauna appears to represent a later stage than the Calvert formation of Maryland. This conclusion is also strengthened by the presence of baleen and balænopterine whales, the diversity of types among the cetotheres, and by the singularly modified beaked whales of the family Ziphiidæ. One can not be certain that the Anversian representatives of genera which are known to have a longer geologic range than some of the others are more advanced than those of the Calvert formation, because adequate material representing the earlier forms either is not available or the critical features can not be found in the published figures or descriptions. One can say with a reasonable degree of certainty that different species of the same genus are present in the two stages, and that the Anversian is further characterized by the sudden influx of a number of modern types.

BONE VALLEY FORMATION OF FLORIDA

(Stage uncertain)

In terms of the Miocene faunas of Europe, the pelagic mammals of the Bone Valley formation of Florida are clearly earlier than Pliocene and not later than Upper Miocene. The widespread Miocene sirenian *Metaxytherium* and the characteristic Miocene long-beaked dolphin, *Schizodelphis*, have been found in this formation. Their known geologic range in Europe extends from the Burdigalian to the Anversian. The presence of the dolphin *Pomatodelphis inæqualis* may suggest the possibility that this deposit is at least as old as the Helvetian, for related species are found in two Helvetian localities in France. Related species of the dolphin *Schizodelphis* and the sirenian *Metaxytherium* also occur in this stage. The other possibility is that they represent more advanced types of these Helvetian genera. No remains of these pelagic mammals have ever been described from Pliocene formations in Europe, nor do they fit into the known Pliocene faunas of Europe or South America. Additional support was given to the later conception by allocating the Bone Valley sperm whale with the Saint Mary's *Diaphorocetus mediatlanticus*. A comparison with the type skull of the last-mentioned species shows that the Florida cetacean represents some other fossil sperm whale. Furthermore, these pelagic mammals do not agree with those known from the Calvert formation of Maryland, nor from the Anversian of Belgium.

Summary

From the foregoing brief review of the subject, the following summary may be given: In the first place, the archaic toothed whales of the Cooper marl and the zeuglodonts of the Jackson formation appear to represent a fauna which came into existence after the Qasr-el-Sagha stage of the Fayum. At present, Oligocene faunas of pelagic mammals are very imperfectly known. There appears to be no reason, as far as may be judged from the present data, why pelagic mammals should not be present in American Oligocene marine formations. The archaic types of toothed whales survived until the beginning of the Miocene. Characteristic Miocene types of cetaceans are first encountered in the Burdigalian stage. Thus far the Miocene formations of the Atlantic coast of North America equivalent in time to the Burdigalian have not yielded remains of pelagic mammals, or at least they have not been described. Typical pelagic mammalian faunas of the Helvetian stage are to be found in France. The cetaceans of the Calvert formation contain representatives of the prevailing Miocene genera, and the assemblage as a whole fits in very well with what might be expected in the interval between the Helvetian of France and the Anversian of Belgium. If any reliance can be placed on the occurrence of pelagic mammals, then the Bone Valley formation of Florida is clearly Miocene. In the light of the types known at present, it does not appear advisable to allocate this formation to any definite stage.

Tertiary cetacean remains appear to be very abundant in a number of localities in North America and Europe. No mention has been made of some of these deposits because most of the genera and species are founded on fragmentary skulls, or on vertebræ, or on teeth. To interpret the relationships of forms thus established is in many cases well-nigh impossible, and to compare American with European forms is not feasible in many instances. Further exploration of these formations and the application of modern collecting methods should furnish material which can be utilized. Fortunately, satisfactory material has been obtained in recent years from at least three American localities, and the material thus obtained is so promising that it is not unreasonable to suppose that intensive fieldwork will produce similar results in other localities. At this time it may be advisable to call attention to the fact that a large portion of the forms now known are based on material obtained from 30 to 100 years ago. Conditions for the comparison of American and European forms are not always as difficult as may be imagined, and in some instances it has been possible to compare teeth with teeth, skulls with skulls, earbones with earbones, and vertebræ with vertebræ.

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AMERICAN TERTIARY TERRESTRIAL PLANTS AND THEIR INTERDIGITATION WITH MARINE DEPOSITS[1]

BY E. W. BERRY

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

Terrestrial plants are found at relatively few localities and horizons as compared with marine invertebrates; so that invertebrate paleontology

[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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has taken the lead in the segregation of the Tertiary and the correlation of the resulting stratigraphic units. Nevertheless, fossil plants are likely to occur in abundance at just the horizons where the remains of marine life are sparingly represented or totally absent, and plants are, moreover, much more sensitive to environmental changes than are aquatic organisms; so that they can not be ignored in discussions of correlation.

Paleobotanical studies are necessarily largely provincial; but let me remind you that the larger questions of the origin, evolution, dispersal, and extinction of floras, as well as other types of organisms, can only be successfully solved by the most precise correlation of strata in distant regions, which is the ample excuse for attempting the solution of a problem of the magnitude of intercontinental correlation.

Although woefully lacking in completeness, nowhere do we find a single region where fossil plants are represented at as many Tertiary horizons as in southeastern North America.

Here there are found a very prolific Lower Eocene flora—that of the Wilcox group; a very considerable Middle Eocene flora—the Claiborne; a still larger Upper Eocene flora—the Jackson; and considerable floras in the Oligocene, Miocene, and Pliocene.

Considerable floras are being discovered in the Tertiary of northern South America, Mexico, Central America, and the Antilles, and I can only hint at the importance of this strategic combination of equatorial and temperate zone Tertiary floras in its bearing on all questions of origin, evolution, and dispersal of the higher plants, which, combined with the presence in this same area of unequaled Lower and Upper Cretaceous floras on the borders of the old Appalachian landmass, renders this region unique in the annals of paleobotany.

The United States

EARLY EOCENE FLORAS

The earliest stage of the Eocene in southeastern North America is prevailingly marine and without plant fossils. A few undeterminable forms have been obtained in Maryland, South Carolina, and west Tennessee, and there are two small florules in Texas whose age is in doubt, but which may prove to be Midway, but these are too small to be of value.[2]

LOWER EOCENE FLORAS (WILCOX)

The Wilcox group contains the largest flora of any Tertiary horizon in this region. It numbers nearly 400 species.[3] The majority of these are

[2] U. S. Geol. Survey Prof. Paper 132E.
[3] U. S. Geol. Survey Prof. Papers 91, 1916; 108E, 1917; 131A, 1922.

peculiar to the area, and their only value for purposes of correlation is that of their stage of development and the environment which they indicate, and in both of these respects they are of importance in correlating with European Tertiary floras.

No richly fossiliferous European plant horizons exactly equivalent to the Wilcox have as yet received monographic study. The Eocene of the south of England is rich in fossil plants at horizons that I consider equivalent to the Wilcox, but comparisons are unfortunately limited to the long lists of *nomina nuda* published by Ettingshausen, to which I will have occasion to refer in detail. It thus happens that the exhaustively studied Sannoisian floras of Provence and the Tyrol, so effectively monographed by Saporta and Ettingshausen, respectively, although considerably younger, have afforded many more elements for comparison with the Wilcox than the Eocene flora of England.

The early Eocene of Europe (Montian and Thanetian stages) includes small floras in England, Belgium, and France, the most extensive being the flora of the *marnes heersiennes* in Belgian Limburg, southeast of Saint Trond, on the road to Liege, so elaborately described by Saporta and Marion; that of the travertines of Sézanne, on the shore of the old lake of Rilly, east of Paris, monographed by Saporta; that of the Trieu de Leval, in Belgium (Hainaut), monographed by Marty; and the small scattered floras in the Thanet sands (grès de Vervins, etcetera) studied by Watelet and recently revised by Fritel, of the Paris Museum. None of these floras are extensive enough for detailed comparisons with the Wilcox. Such comparisons as are possible show that the Wilcox is younger than the Montian or the Thanetian, whose floras are more similar to those of the early Eocene of the western interior region of the United States and are at least partly represented in the embayment area by the deposits of the Midway group. The one feature of noticeable parallelism between these early Eocene floras of Europe and that of the Wilcox is the abundant and strikingly similar species of Dryophyllum in each.

The next succeeding stage of the European section is the Sparnacian, which contains fossil plants in the "argile plastique" and the "lignites du Soissonnais" of the Paris basin. The old work of Watelet has recently been revised by Fritel, and though the flora is still relatively small (less than 150 species) it shows resemblance to the Wilcox in species of Asplenium, Taxodium (identical), Sabalites, Arœcites, Ficus, Laurus, Cinnamomum, Aralia, and Sapotacites. The Woolwich and Reading beds of West Kent, Surrey, and Sussex, in England, of this age, contain a mostly undescribed flora of somewhat more temperate facies than that of the

Wilcox, though they afford comparable forms in the genera Lygodium, Asplenium, Ficus, Laurus, Aralia, and Sabalites. I regard the Wilcox as partly the equivalent of the Sparnacian, although the evidence for this correlation can not be considered conclusive. The succeeding stage of the European section, the Ypresian, yields an extensive flora. Though this flora is not very rich in the grès de Belleu of the Paris basin (150 species), it is very representative in the pyritized seeds and fruits of the London clay on the Isle of Sheppey and in the pipe clay of Alum Bay on the Isle of Wight.

The flora of the grès de Belleu has comparable species of Lygodium, Sabalites, Cannophyllites, Juglans, Myrica, Artocarpidium, Ficus, Anona, Persea, Laurus, Dryophyllum, Cercis, Banisteria, Anacardites, Apocynophyllum, Chrysophyllum, Diospyros, Magnolia, Grewia, Terminalia, Eugenia, Gleditsia, Cæsalpinia, Entada, and Leguminosites.

Ficus schimperi is much like *Ficus cuspidata* Watelet, *Oreodaphne mississippiensis* is represented by *Laurus attenuata* Watelet, *Mespilodaphne coushatta* by *Persea regularis* Watelet, *Cercis wilcoxiana* by *Cercis deperdita* Watelet, *Gleditsiophyllum fructuosum* by *Acacia brongniarti* Watelet, *Gleditsiophyllum entadaformis* by *Entada dubia* Watelet, *Banisteria pseudolaurifolia* by *Banisteria juglandoides* Watelet, and *Bumelia americana* by *Piscidia protogea* Watelet.

The European flora most similar to that of the Wilcox appears to be that of Alum Bay and the Isle of Sheppey, although this comparison rests on the long list of names (nearly all *nomida nuda*) representing Ettingshausen's preliminary studies of these floras which were never brought to completion. These lists were republished by me in Professional Paper 84.

The Alum Bay flora includes about 275 species in 116 genera and 63 families and comprises 3 thallophytes, 2 ferns, 5 gymnosperms, 6 monocotyledons, and 97 dicotyledons. It is thus less extensive than the Wilcox. Nevertheless, the Wilcox flora contains the following 39 genera in common with that of Alum Bay (Isle of Wight):

Anemia	**Pisonia**	**Bombacites**
Glyptostrobus	**Aristolochia**	**Ternstroemites**
Cyperites	**Fraxinus**	**Grewiopsis**
Sabalites	**Sapotacites**	**Sapindus**
Myrica	**Bumelia**	**Cupanites**
Ficus	**Diospyros**	**Dodonæa**
Juglans	**Aralia**	**Cedrela**
Banksia	**Cornus**	**Celastrus**
Cinnamomum	**Magnolia**	**Ilex**
Laurus	**Anona**	**Zizyphus**

Rhamnus	Leguminosites	Cassia
Eugenia	Sophora	Acacia
Dalbergia	Cæsalpinia	Mimosites

The following 36 Wilcox families are represented at Alum Bay:

Pinaceæ	Tiliaceæ	Euphorbiaceæ
Palmæ	Sterculiaceæ	Anacardiaceæ
Juglandaceæ	Bombacaceæ	Ilicaceæ
Myricaceæ	Ternstroemiaceæ	Celastraceæ
Fagaceæ	Myrtaceæ	Sapindaceæ
Moraceæ	Melastomataceæ	Araliaceæ
Proteaceæ	Lauraceæ	Cornaceæ
Aristolochiaceæ	Mimosaceæ	Sapotaceæ
Nyctaginaceæ	Cæsalpiniaceæ	Ebenaceæ
Magnoliaceæ	Papilionaceæ	Oleaceæ
Anonaceæ	Meliaceæ	Apocynaceæ
Rhamnaceæ	Malpighiaceæ	Verbenaceæ

Not only are these families represented in both floras, but the general facies and that of each family are much the same. Thus there are 42 species of Leguminosæ at Alum Bay, and the next most abundant families are the Moraceæ, Lauraceæ, Sapindaceæ, Myrtaceæ, and Celastraceæ, just as in the Wilcox. Furthermore, on both sides of the Atlantic these floras show identical climatic conditions and both include a large number of genera and families that contain allied species which appear for the first time.

Comparisons are not as easily made with the Sheppey flora, since it consists entirely of fruits and seeds. Notwithstanding these difficulties, it may be noted that three Wilcox species, the most positively identified as well as the most significant of which is *Nipadites burtini umbonatus*, are identical with Sheppey forms and still others are closely allied to Sheppey forms. In addition, the following 21 Wilcox genera are represented in the Sheppey flora: Cyperites, Canna, Sabalites, Dryophyllum, Juglans, Euphorbiophyllum, Proteoides, Laurus, Nyssa, Apocynophyllum, Solanites, Sapotacites, Diospyros, Magnolia, Sapindus, Cupanites, Eugenia, Myrcia, Leguminosites, Mimosites, and Carpolithus. Monocarpallites of the Wilcox is believed to be the same as Hightea of Sheppey.

Thus between the Wilcox flora and the combined flora of Sheppey and Alum Bay the closest sort of a parallel exists.

In view of the foregoing discussion, I have no hesitation in making the most positive statement that the Wilcox flora is largely of Ypresian age.

The Midway (?) and Wilcox floras cover the paleobotanical history of southeastern North America during the basal and Lower Eocene. In terms of European geology, this corresponds to the stages Montian,

Thanetian, Sparnacian, and Ypresian. Together these stages correspond to the Eonummulitic of Haug (1911), to the Suessonian of d'Orbigny, and to the Paleocene of Schimper[4] (1874).

MIDDLE EOCENE FLORAS (CLAIBORNE)

The Claiborne and Jackson cover the balance of the Eocene in southeastern North America. The deposits of these groups with the intervals between the Wilcox and Claiborne and between the Claiborne and Jackson correspond to the stages Lutetian, Auversian (Ermenonvillian), Bartonian, and Ludian of the European section. Together these correspond to the Mesonummulitic of Haug (1911) and to the Parisian of d'Orbigny.

I regard the evidence of an emergence interval between the Wilcox and the Claiborne as entirely convincing. This evidence has been partially given in previous reports.[3 5] It rests on a considerable body of facts in which the conclusions from all the different classes of evidence are in perfect agreement. The withdrawal of the Wilcox strand-line to the southward is indicated by the littoral character of the upper Wilcox materials; the presence of palustrine deposits in these littoral sands and clays, as in the Bolivar Creek section of Arkansas; in the thickening of the Wilcox down the dip; in the observed unconformities between the Wilcox and the Claiborne recorded from Georgia, Mississippi, and Texas; in the great changes in the marine faunas and terrestrial floras in passing from the Wilcox to the Claiborne; and in the littoral character of the lower Claiborne as exemplified by the Tallahatta Buhrstone in the eastern Gulf area and the Mount Selman sandstone in the western Gulf area. Only 10 out of the 500 known Wilcox and Claiborne species pass from Wilcox to Claiborne. I consider that this interval corresponds approximately to the lower Lutetian of Europe (corresponding to what Dollfus in 1880 called Parnian and Calvimontian).

The Middle Eocene in Europe was a time of positive movements of the strand, with widespread submergence, especially of the Mediterranean, which stretched from Vienna to Khartoum. This extensive transgression was not especially favorable for the preservation of terrestrial organisms. Middle Eocene floras are not nearly as extensive as might be wished for, and where plants do occur in beds of this age they are either undescribed, like those of southern England, or very inadequately described, like those of northern Italy.

[4] Not of Von Koenen, Dollo, etc., which is limited to the Montian stage.

[5] E. W. Berry: U. S. Geol. Survey Prof. Paper 91, pp. 47-38; Prof. Paper 95F, 1915, pp. 78-80.

Bureau[6] has described a few plants, including Pandanus, Flabellaria, Sabal, Yucca, and Nuphar, from these beds in the Paris basin, and at Trocadero, near Paris, an estuary flora, largely undescribed, but including Euphorbiophyllum, Nerium, Ottelia, Pandanus, Nipadites, Zizyphus, etcetera, has been recorded.

In the south of England the plants of the Bagshot sands and Bournemouth clays have never been carefully described, although the ferns and gymnosperms were rather fully treated by Ettingshausen and Gardner. The ferns number 18 species and include a fine Acrostichum, a tropical Gleichenia, a striking Goniopteris, a species of Hewardia close to existing forms of Central America, the same species of Lygodium that occurs in the Claiborne, and various other genera of a tropical character. The conifers include Araucaria, Glyptostrobus, Pinus, Podocarpus, Athrotaxis, and Sequoia. The palms, still undescribed, are said to include Iriartæa, Phœnix, Calamus, and Nipa. The dicotyledons, of which there are many, all undescribed, are said to include Ficus, Myrica, Cinnamomum, Dioscorea, and the tropical genus Godoya.

The lower Lutetian flora from the classic locality of Monte Bolca, in Venetia, Italy, is the most extensive known from this horizon. As somewhat overelaborated by Massalongo, it contains 125 species. Six of these are gymnosperms (5 species of Podocarpus and 1 species Taxodium). There are 33 monocotyledons, mostly of but slight value, and few palms. There are 86 dicotyledons and no ferns, and the general facies is not only very different from that of the Claiborne flora, but almost equally unlike the flora of the upper Lutetian of Italy.

The upper Lutetian flora of Novale, in Venetia, is quite different from the lower Lutetian flora just mentioned. As elaborated by Visiani and Massalongo, it contains 138 species. These include 5 Thallophytes; 4 ferns, including Acrostichum and Pteris; 4 gymnosperms, 15 monocotyledons, including Arundo and Potamogeton, and many dicotyledons. There are 23 species of Leguminosæ and species of Myrica, Ficus, Laurus, Cinnamomum, Sapindus, Cupanites, Celastrus, Zizyphus, Aralia, Eugenia, Myrcia, Dalbergia, Cæsalpinia, Cassia, Inga, Bumelia, Diospyros, etcetera.

This flora is distinctly like that of the Claiborne in its general composition, and the same remark is true of the small florules from the Auversian of Ronca, Vegroni, and other localities in Venetia, which include species of Acrostichum, Coccolobis, Laurus, Terminalia, Apocynophyllum, Cinnamomum, Dombeyopsis, etcetera.

[6] E. Bureau: Études sur la flore fossile du calcaire grossier parisien. Mém. Soc. Philom., 1888, pp. 235-264, pls. 22-23.

The known Claiborne flora[7] totals about 100 species, which, except for a small florrule from the basal Claiborne of the Rio Grande region of Texas (Mount Selman formation), comes from the middle and upper Claiborne (Lisbon, Gosport, and Yegua formations); hence the correlation based on the flora does not mean that the Claiborne group as a whole may not represent a somewhat longer Middle Eocene interval than the flora indicates.

It seems conclusive that the Claiborne flora is younger than known lower Lutetian floras, but that it does show considerable resemblance to floras from the upper Lutetian and Auversian (= Ermenonvillian). I therefore reach the conclusion, admittedly tentative, that the known Claiborne flora of southeastern North America indicates an age corresponding largely to the Auversian stage (Dollfus, 1880) of European geology [= Lower Bartonian (Munier-Chalmas and De Lapparent, 1893), Ermenonvillian (Dollfus, 1880), Valoisian (Paul Combes fils, 1906), Ledian (Mourlon, 1893)].

In connection with the Middle Eocene it should be pointed out that there is a considerable identical element (when the distance and different environmental conditions are considered) in the Green River of Wyoming. Vertebrate paleontologists have correlated the Green River with the Ypresian stage. Paleobotanically, the Green River and Wind River (considerable flora) are entirely unlike the Wilcox (Ypresian). Hence these Wyoming deposits represent Lutetian or Auversian, or possibly both of these stages.

UPPER EOCENE FLORAS (JACKSON)

The Jackson flora[8] is a coastal flora amounting to 133 species. Eighteen per cent of the 225 species of the combined Claiborne and Jackson floras are common to both stages.

The geologic history indicates a more or less extensive withdrawal of the sea, but slightly reflected in the sediments of southern Alabama, but prominent from Mississippi to Mexico in the littoral, palustrine, and continental deposits of the Yegua formation. Partially contemporaneous with these continental deposits of late Claiborne time, there was a marked transgression of the lower Jackson Sea from Georgia to Arkansas and a less pronounced transgression in the Texas region indicated by the occasional marine horizons in the Fayette sandstone and Frio clay. In Mississippi the Jackson closes with a deposit of littoral plant-bearing sand—the Forest Hill sand, partly continental and apparently partly

[7] U. S. Geol. Survey Prof. Paper 92 (In press).
[8] U. S. Geol. Survey Prof. Paper 92 (In press).

contemporaneous with the marine Red Bluff clay of the lower Vicksburg. That there was such an oscillation of the strand-line between the Jackson and the Vicksburg is indicated by the character of the Forest Hill sand, by the palustrine lignites often present at the base of the Vicksburg, and by the enormous thickness of the Jackson down the dip, as shown by the well borings in western Mississippi and eastern Louisiana, in the region around Vicksburg.

The Forest Hill sand is considered by Cooke[9] to be contemporaneous with the Red Bluff clay, although he admits their relations are not definitely known. The only known fossils in the Forest Hill sand are plants, and these indicate a Jackson, and not a Vicksburg, age. In the Texas region no such pronounced migrations of the strand-line are discernible, but there appears to have been an oscillation permitting continental deposits to interfinger with shallow marine deposits less pronounced, but comparable to the sequence of contemporaneous events in the Paris basin which resulted in the gypsum deposits of the Ludian stage.

This oscillation in Texas was prevailingly negative in character, resulting in the continuation of the continental type of sediments of the Fayette sandstone throughout the greater part of Vicksburg time in that region. These receive the name Catahoula sandstone and are distinguished with difficulty from those of the underlying Fayette.

This history as thus briefly outlined is graphically summarized in the accompanying text figures.

In a preceding paragraph I have shown that there is satisfactory evidence for correlating the Claiborne flora with the Auversian or lower Barton of the European section. The Jackson flora is then to be compared with that found in the Upper Eocene of Europe.

The Upper Eocene of Europe, variously denominated in various countries, comprises in the Paris basin the Bartonian below, named by Mayer Eymar in 1857 from the Barton sand and clay of southeastern England, and the Ludian above (Munier-Chalmas and De Lapparent, 1893). In England the latter is represented by the glass sands, or Headon series, containing a few Chara fruits, a Folliculites, and an unnamed feather palm. In the Paris basin the Bartonian marks a slight transgression of the sea, less in extent than that of the preceding Auversian or the subsequent Ludian. The latter represents a considerable transgression and then an oscillation of the strand that permitted the formation of the successive gypsum beds for which that region is celebrated. In Belgium the corresponding stages are typically marine and are termed the Wemmelian (*sensu stricto*) and the Asschian (Rutot 1882), respectively. In

[9] C. W. Cooke: U. S. Geol. Survey Prof. Paper 133, 1923, p. 1.

the region of the Alps deposition was continuous, but the Ludian transgresses somewhat beyond the borders of the underlying Eocene. In the latter region the Upper Eocene is often considered as a unit under the term Priabonian, from Priabona, in the Venetian Alps. The recorded fossil floras from the Upper Eocene of Europe have been extremely limited and fragmentary; so that there has been little that afforded any basis for comparison with the Jackson flora, which, small as it is, is much

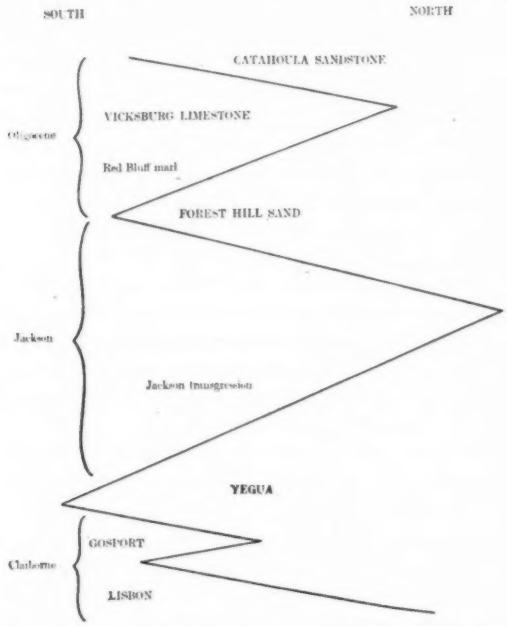

FIGURE 1.—*Diagram showing Movement of Strand-line and the Relation of the geological Formations in the central Area of the Mississippi Embayment*

larger than any contemporaneous European flora, with the exception of the Messel flora from Hesse. The latter, described recently in a posthumous paper by Engelhardt,[10] comprises representatives of 66 families, 154 genera, and 346 nominal species. There are no elements exactly identical with those of the Jackson, but the two have a considerable number of closely related species, and a large number of the genera are common to both floras. The Hesse flora differs from that of the Jackson

[10] H. Engelhardt: Abh. Hess. Landes, Bd. 7, Hft. 4, 1922.

in the large number of forms that it contains that are referred to Quercus, in the large number of species of Ficus, members of the Proteaceæ and Myrtaceæ, and in the presence of certain Old World genera, such as Amomum, Doliostrobus, Laurelia, Leptomeria, Elæagnus, Ligustrum, Notelæa, Mæsa, Cunonia, Ceratopetalum, Callicoma, Knema, Coriaria, Pomaderris, Anaphremum, Mangifera, Tristania, Callistemon, and Acmena.

The celebrated Oligocene flora (Sannoisian or Stampian) from the gypsiferous shales of Provence, with which the town of Aix is insepar-

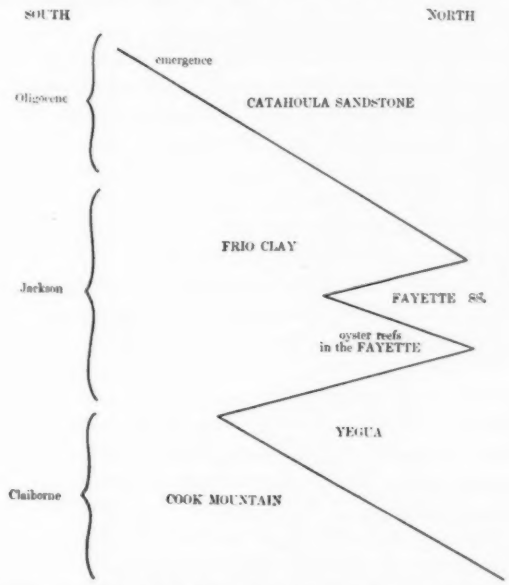

FIGURE 2.—*Diagram showing the Movement of the Strand-line and the Relation of the geological Formations in the Texas Area*

ably associated, was considered by Count Saporta, its describer, as of Upper Eocene age. It is very extensive and includes several hundred species. There seems to be little doubt but that it is not older than Lower Oligocene, and that it may even be Upper Oligocene. The fact that it differs from the large Sannoisian flora of Liguria[11] suggests the latter alternative; so that it is conclusively recognized as somewhat younger than the Jackson flora. There are some Upper Eocene floras in

[11] P. Principi: Mem. serv. carta Geol. d'Italia, vol. 6, 1916; vol. 7, 1921.

northern Italy, but they are poorly described, and as the term Ligurian, to which they are often referred, includes both Eocene and Oligocene horizons, it has not been possible to utilize them for precise correlation purposes.

There remains for comparison the small flora described by Saporta,[12] from Brives, in Velay, and the plants recorded by Crié[13] from the Upper Eocene sandstones of Maine and Anjou. The Brives flora is small, comprising but 21 species, and although it contains some of the genera found in the Jackson—for example, Sabalites—its chief interest is in that it contains a well marked date palm referred by Saporta to the existing genus Phœnix, thus paralleling the Jackson date palm referred to Phœnicites. Saporta referred the Brives flora to the Lutetian, but I follow De Lapparent (1906) in considering it Bartonian in age. The plants described by Crié from the Sabalites sandstones of Maine and Anjou, in western France, are of especial interest, since the leaves of the fan palms, sometimes found in an upright position in these sandstones, indicate their burial by subaerial wind-blown sands, and the physical conditions appear to have been much the same as those concerned with the formation of the Fayette sandstone of Texas, where similarly preserved palms are found. This flora numbers 55 species and includes 5 ferns, 5 palms, 3 gymnosperms, and various dicotyledons. Genera common to the Jackson are Lygodium, Sabalites, Myrica, Ficus, Diospyros, and Apocynophyllum.

There is thus little evidence for precise intercontinental correlation with the Jackson. It is safe to say that it is Priabonian in age, but whether upper or lower remains inconclusive. Thus, in so far as the paleobotanical evidence is concerned, the Jackson flora may be Bartonian or it may be Ludian in age.

The widespread Tertiary floras of the Arctic region, which extend to within a few degrees of the pole, may be mentioned at this point. Described by Heer as Miocene, it has long been recognized that they were older. There is considerable evidence for correlating them with the Jackson-Vicksburg of southeastern North America. The actual resemblance between the Jackson and these Arctic floras is very slight. In the case of the Jackson, it is confined to the single wide-ranging species *Taxodium dubium*. If the temperate floras of the far north were contemporaneous with the moist warm climate floras of southeastern North

[12] Gaston de Saporta: Essai descriptif sur les Plantes Fossiles des arkoses de Brives pres le Puy-en-Velay. Ann. de la Soc. d'agr. sci., etc., du Puy, vol. 33, 1878, pp. 1-72, pls. 1-6.

[13] L. Crié: Recherches sur la végétation de l'ouest de la France à l'epoque tertiaire. Ann. sci. géol., vol. 9, 1877, pp. 1-72, pls. 8-22.

America, namely, the Jackson, Catahoula, and Vicksburg, as seems probable, this lack of specific resemblance is just what should be expected, and these Arctic floras of Jackson or Vicksburg age should contain, as they actually do, a number of types that existed in the Gulf region during Lower Eocene times. Moreover, if their greatest extension was contemporaneous with the time of Jackson to Vicksburg, they should contain other types that are found subsequently at later horizons in lower latitudes; and in this also they fulfill the requirements of the case, as has already been pointed out by Count Saporta and J. Starkie Gardner, the evidence for which has increased since these authors wrote.

OLIGOCENE FLORAS (CATAHOULA-VICKSBURG)

The Oligocene flora of southeastern North America, unlike the widespread and rich Oligocene floras found in continental deposits of that age in Europe, are limited to about 30 species found in the Catahoula and Vicksburg formations.[14] These are peculiar to the area. One petrified palm is identical with an Oligocene species of Antigua, and two others are close to, or identical with, Antiguan species, affording a welcome corroboration of the age of the Antiguan beds. Specifically, the Catahoula-Vicksburg flora can not be directly compared with Europe, but in its general facies is very much like that of the abundant floras in the Oligocene of Provence, Tyrol, Dalmatia, and Styria, both containing a generic assemblage not found in the temperate zone in beds of post-Oligocene age.

In correlation table of Vicksburg published by Cooke (op. cit.) the Catahoula is correlated with the Aquitanian of Europe. Aside from the propriety of including the Aquitanian of Europe in the Oligocene, the Catahoula flora appears to be distinctly older than Aquitanian. There are very abundant floras in Europe in both the Chattian and Aquitanian stages, but our limited American Oligocene floras show more resemblance to European Mediterranean floras generally considered to be older than either of these stages—that is, Stampian (Rupelian) in age.

MIOCENE FLORAS

The Lower Miocene flora of southeastern North America is limited to 13 described species from the Alum Bluff sands of Florida and the Hattiesburg clay of Mississippi.[15] It is much too limited to afford data for precise correlation. It is, however, entirely distinct from the preceding Oligocene flora of the region. In terms of European floral succession,

[14] U. S. Geol. Survey Prof. Paper 98M, 1916.
[15] U. S. Geol. Survey Prof. Paper 98E, 1916.

it is clearly younger than the Stampian (Rupelian) floras and older than the Helvetian floras of Europe. This narrows the correlation, in so far as the plants are concerned, to the Chattian (Kasselian), Aquitanian, and Burdigalian (Langhian, Mayencian) stages. The Alum Bluff flora is not Chattian in age, but may be either Aquitanian or Burdigalian. The floral evidence is too incomplete to reach a conclusion, although such as it is there is a slight preponderance of evidence in favor of Aquitanian.

The later Miocene flora of southeastern North America is confined to a small coastal and dune flora found in the Calvert formation.[16] This comprises only 27 species, but affords convincing evidence of the attendant physical conditions. Seven of the Calvert plants are common to the Tortonian of Europe and 10 others are close to Tortonian species; so that the floral evidence points rather strongly to the Tortonian age of the Calvert. Both are believed to have invaded the region in which they are found from a more northern and more or less common source, and the fact that five of these Calvert forms are similar to or identical with plants found in the earlier Tertiary of Greenland which I regard as equivalent to the Jackson-Vicksburg lends considerable support to this view.

PLIOCENE FLORAS

The Pliocene is represented by a considerable, but as yet almost wholly undescribed, flora in southern New Jersey which may really be as old as the Sarmatian of the European Miocene, and by about a score of species from the Citronelle formation of southern Alabama.[17] The latter afford no direct points of contact with European floras, but is decisively Pliocene and, in my opinion, belongs in the later half of the Pliocene.

Equatorial America

GENERAL STATEMENT

The account of the fossil floras at present known from equatorial America is more in the nature of a brief summary than a contribution to their correlation, but is important in calling attention to the gaps in our knowledge. In particular, larger collections are greatly to be desired, and it is believed that these would have also an important bearing on the question of former land connections. We can look forward to a much more complete knowledge of the Equatorial Paleobotanical section in the not-distant future.

[16] Idem., 98F, 1916.
[17] U. S. Geol. Survey Prof. Paper 98L, 1916.

MEXICO

Passing southward from the United States in North America, the first Tertiary flora to be encountered is that described recently from the Isthmus of Tehuantepec.[18] This is an extensive flora of which a preliminary account only has been given. It is interbedded with strata containing an extensive marine fauna—the so-called Santa Rosa fauna—on which we will have to rely for the final determination of age. The flora, as published, comprises 33 species, 29 of which are known only from this area. Of the others, three are common to Costa Rica, one to Colombia, and one to Haiti and the Dominican Republic. Neither the flora nor the fauna appears to me to be as old as the Burdigalian stage, and I consider the flora to be, in all probability, referable to the Helvetian stage—that is, Middle Miocene.

COSTA RICA

A small Miocene flora of 12 species, 9 of which were new to science, has been described from Costa Rica.[19] One of these Costa Rican forms is found in Panama and two occur in the Santa Ana beds of Colombia. The associated Mollusca enable us to correlate these plant-bearing beds of Costa Rica with the Gatun formation of Panama, and with the Helvetian stage of the European Miocene. The local section consists of the Suretka conglomerate at the top, underlain by the littoral and lignitic continental deposits of the Gatun which interfinger with the marine fossiliferous beds of this formation, and these in turn underlain by the Uscari formation—a series of dark shales, sandstones and limestones containing limited mollusca faunas and a considerable number of Foraminifera. The Uscari is rather definitely correlated with the Baiton and Cercado formations of Santa Domingo and with the Burdigalian stage of Europe.

PANAMA

Several Tertiary horizons in and near the Canal Zone in Panama have furnished small florules.[20] A single petrified species of Diospyros from Tonosi is late Middle Eocene. There are 14 species recorded from the Bohio, Emperador, Caimito, Cucuracha, and Culebra formations which I regard as Oligocene or Lower Miocene (Aquitanian) and five species from the Gatun formation which are considered to indicate a Helvetian age. All of the fossil plants from Panama, except two species based on

[18] E. W. Berry: U. S. Nat'l Museum Proc., vol. 62, 1923, Art. 19.
[19] E. W. Berry: Idem., vol. 59, 1921, pp. 169-185, pls. 22-27.
[20] E. W. Berry: U. S. Nat'l Museum Bull. 103, 1918, pp. 15-44, pls. 12-18; Idem., Proc., vol. 59, 1921, pp. 21-22.

silicified woods, and which are common to Antigua, are unknown outside of the Isthmus.

COLOMBIA

The fossil plants from Colombia comprise considerable floras, described by Engelhardt,[21] from Santa Ana, in the Magdalena Valley, and from Buga, in the Cauca Valley. The former is fairly extensive, comprising 40 species, but, beyond its reference to the Miocene, nothing is known of its precise horizon.

I have considerable unpublished material from Colombia from the following localities: Cipacón, Guasca, Guadalupe, Cundinamarca, Huila, Tequendama, Tolima, and Leiva. The plants from the first of these is probably Upper Eocene, those from the last are Miocene or younger, and the balance are probably Miocene.

VENEZUELA

A small florule of 16 species has been described from the northern border of the Cordillera de Merida,[22] south of Lake Maracaibo, in Venezuela. These are all new to science except two which are common to Santa Ana, Colombia. This Venezuelan florule is not older than the Helvetian stage of Europe and may be slightly younger.

TRINIDAD

I have rather extensive collections of fossil plants from the Island of Trinidad which have not yet been described in print. These represent four horizons. The oldest of these is from the Forest clay and sand of the southern part of the Southern depression. It comprises about a dozen species of tropical rain-forest forms, such as Anona, Persea, Guajacum, Bursera, etcétera, is correlated with the marine Cyclammina clay of the island, and is probably Burdigalian in age.

The second is a small florule from the Morne l'Enfer beds of the southwestern part of the island. These are correlated with Guppy's Manzanilla beds and are probably to be correlated with the Gatun formation of Central America. I regard the plants as Helvetian in age.

The third florule comes from the so-called Upper Miocene of Trinidad. The plants are numerous and well preserved in the natural burnt clay known as porcellanite, and belong in what Wall and Sawkins called the Caroni series.[23] They include representatives of the genera Pisonia,

[21] H. Engelhardt: Abh. Senck. Naturf. Gesell., Band 19, 1895.

[22] E. W. Berry: U. S. Nat'l Museum Proc., vol. 59, 1921, pp. 553-579, pls. 107-109.

[23] G. P. Wall and J. G. Swakins: Report on the geology of Trinidad. Mem. Geol. Survey Great Britain. London, 1860.

Coccolobis, Nectandra, Bumelia, Cedrela, Calophyllum, Coussapoa, Clusia, Lecythidoanthus, and various leguminous leaflets. These plants are not older than Helvetian and may be slightly younger.*

The fourth florule is from the Oropouche beds of the southern part of the island and comprises a typical mangrove association with many leaves of Rhizophora, a few of Avicennia and Coccolobis, and several of Clusia, Exostema, Pithecolobium, Bumelia, etcetera. The age indicated is either late Pliocene or Pleistocene.

ANTIGUA

The Oligocene of the Island of Antigua contains a large amount of silicified wood, long celebrated in the annals of Paleobotany and frequently mentioned since the days of Scheuchzer (1723). The only elaborate account of these is in a paper by Felix,[24] a generation ago. Large collections made by Vaughan have received only a preliminary study. Two of Felix's species have been found in the Panama Canal Zone, and a third is not uncommon in the Catahoula and Vicksburg of the southeastern United States.

PORTO RICO

The New York Academy of Sciences studies in Porto Rico have resulted in some small and rather poorly preserved fossil plants from several geologic horizons, but these have not yet been described.

HAITI

The Island of Haiti has yielded fossil plants from both of its political divisions. The flora from the Dominican Republic[25] comprises 15 species, of which but one has an outside distribution, being found in Haiti and Mexico. This flora is either Middle or Upper Miocene in age. The Republic of Haiti has furnished undeterminable plants from both the Cretaceous and the Eocene. Nine species have been described from the Miocene,[26] mostly from the Artibonite group. The age of these has not been determined more precisely than Miocene, although they belong in the later rather than the earlier Miocene.

* Since this was written Hollick has published a review of the fossil floras of the Antilles and described species from Porto Rico, Trinidad, Haiti, and Cuba, but no correlations are attempted. Bull. N. Y. Bot. Garden, vol. 12, no. 45, 1924.

[24] J. Felix: Die Fossilen Hölzer Westindiens. Samm. palæont. Abh., ser. 1, heft 1. Cassel, 1883.

[25] E. W. Berry: U. S. Nat'l Museum Proc., vol. 59, 1921, pp. 117-127, pl. 21.

[26] E. W. Berry: Idem., vol. 62, 1922, Art. 14.

JAMAICA

I have petrified wood and a few undeterminable leaves from the Bowden beds of Jamaica, associated with the extensive marine fauna monographed by Woodring and Helvetian in age.

CUBA

Felix (loc. cit.) recorded petrified wood from Cuba of unknown Tertiary age, and I have a few specimens of leaves found in travertine that are probably of Pleistocene age.

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AMERICAN AND EUROPEAN TERTIARY LARGER FORAMINIFERA[1]

BY T. WAYLAND VAUGHAN

(Read before the Paleontological Society December 27, 1923)

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[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

Manuscript received by the Secretary of the Society September 2, 1924.

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Introduction

American Tertiary species of the following genera are here briefly considered: *Nummulites, Operculina, Heterostegina, "Orthophragmina,"* under which are included *Discocyclina, Asteriacites,* and *Pseudophragmina, Lepidocyclina* and its allies, *Helicolepidina* (*Spiroclypeus*), *Miogypsina, Orbitoclypeus ?, Dictyoconus, Orbitolites ?, Orbiculina, Sorites, Peneroplis,* and *Alveolina.*

The records of the American species as given in this paper are not complete. I have selected for reference only those publications which seemed essential for nomenclatorial and stratigraphic purposes, and in order to make the bibliography as short as possible I have listed only the later comprehensive papers and in them fuller references must be sought. For instance, the titles of the papers by Schlumberger are contained in the memoirs by P. Lemoine and R. Douvillé. I have also omitted references to the volumes on the geology of the Dominican and Haitian republics and to important papers by L. Rutten, A. Tobler, and others. I trust, however, that I have included enough to meet the purpose of this dissertation, which is to give an account of the American Tertiary larger foraminifera from the stratigraphic point of view and to indicate the general relations of the organisms to those found in the Tertiary deposits of Europe.

The study, the results of which are here reported, is not nearly so thorough as I wish it were. This may be considered a report of progress. I have paid more attention to *Lepidocyclina* and its allies than to any other group. Of the species belonging to this group I have had made or have myself made preparations to show the embryonic and meridional

chambers of all species of which there was sufficient and proper material, and nearly all of the preparations have been photographed. Of some preparations I have made camera lucida drawings. Except some of the species from Trinidad, *L. giraudi* from Martinique, and a few species from Panama described by H. Douvillé, none of the accounts of the embryonic and meridional chambers of American species are quoted; all are based on my own observations. Professor Douvillé, however, had, prior to me, recognized the nature of the embryonic chambers of *L. supera, L. floridana,* and *L. ocalana.*

Professor Douvillé has vacillated in his stratigraphic interpretations and has committed a number of errors in his stratigraphic references. These matters will not be discussed in detail, because to do so would unduly expand this paper. He still (1924) refers *Lepidocyclina mantelli* to the Upper Eocene, although the species has not yet been found in deposits of Eocene age. Professor Douvillé's researches on the morphology of the tests of the orbitoid foraminifera are of great value, the most important yet made, but he has not helped in ascertaining the stratigraphic relations of the American species of larger foraminifera.

NUMMULITES

The following species referred to Nummulites have been described from America:

Nummulites floridanus Conrad, 1846, Sherborn Index, page 255 (*Sorites?*).
Nummulites floridensis Heilprin, 1845, Sherborn Index, page 255 (*Operculina*).
Nummulites heilprini Hantken, 1886, Sherborn Index, page 257 (*Operculina*).
Nummulites mantelli Morton, 1833, Sherborn Index, page 259 (*Lepidocyclina*).
Nummulites willcoxi Heilprin, 1882, Sherborn Index, page 266 (*Operculina*).
Nummulites panamensis Cushman, 1918*b*, page 98 (*Operculina*).
Nummulites davidensis Cushman, 1918*b*, page 98 (*Operculina*).
Nummulites antillea Cushman, 1919, page 51 (*Operculina*).
Nummulites parvula Cushman, 1919, page 51, plate 4, figure 3 (not figures 4, 5, 6).
Nummulites sp. Cushman, 1922*b*, page 100. This species is of Operculinoid aspect.

H. Douvillé mentions *Nummulites* in several of his papers on American foraminifera, namely: *Nummulites* sp., similar to *N. striatus,* 1915, page 91; small *Nummulites,* 1915, page 91; *Nummulites* sp. cf. *N. striatus,* cf. *N. irregularis,* and cf. *N. vascus,* 1917, pages 842, 845, 846, 847; and he has made other records.

I have not seen the specimens from Trinidad studied by Professor Douvillé, but, as I have examined large collections from the Coastal Plain

of the United States, Mexico, Central America, northern South America, and the West Indies, I shall base my remarks on the material I have personally studied.

The list above given shows that of the American species originally described as *Nummulites* only one, *N. parvula* Cushman, from the Eocene of Saint Bartholomew, West Indies, is definitely retained in the genus. I have specimens of a small, undescribed species from the Upper Eocene of Mexico, and specimens of another small species from the Oligocene Glendon formation in Florida. A larger species, about 6 millimeters in diameter and 1.8 millimeters thick through the center, from the Upper Eocene of Jamaica, may be a true *Nummulites*, but, as I have been able to study only a vertical section, I am not certain as to the genus.

There are in the Eocene and Oligocene deposits of America many specimens of small nummulitoids, which have not been critically studied. They possess the general aspect of *Paronæa*, *Bruguieria*, and *Laharpeia*, but an attempt to classify them generically would at present be premature.

In America small *Nummulites* or nummulitoids range stratigraphically from Upper or even Middle Eocene into the Oligocene, at least as high as the Middle Oligocene; but no species of *Nummulites* of the facies of *N. lævigatus*, *N. aturicus*, etcetera, have been found in America so far as I know, and no species of *Assilina* are known from there.

Operculina

Cushman, 1920*b*, recognizes the following species of *Operculina* from America:

Operculina cookei Cushman, Upper Eocene.
Operculina vaughani Cushman, Upper Eocene.
Operculina antillea (Cushman), Upper Eocene.
Operculina ocalana Cushman, Upper Eocene.
Operculina willcoxi (Heilprin), Upper Eocene.
Operculina floridensis (Heilprin), Upper Eocene.

Nummulites davidensis Cushman, 1918*b*, page 98, from the Eocene of David, Panama, is also an *Operculina*, and *Nummulites panamensis* Cushman, from the Culebra formation of Panama, probably should be referred to *Operculina*, as it seems to be congeneric with *Nummulites cummingii*, which is now considered an *Operculina*. *Nummulites heilprini* Hantken, 1886 (see Sherborn Index, page 257), is probably an *Operculina*. It is closely related to *O. willcoxi* (Heilprin).

Besides the species above noted, I have in my possession four—perhaps more—new species of *Operculina* from the Tertiary formations of Amer-

ica. They are as follows: (*a*) A small, loosely coiled species from the Upper Eocene of the State of Puebla, Mexico; (*b*) an involute, flat species, also from the Upper Eocene of the State of Vera Cruz, Mexico; (*c*) a small involute species from the Middle Oligocene Meson formation of Mexico and the Antigua formation of Antigua; (*d*) a loosely coiled species from the Miocene Tuxpan formation of Mexico. There may be more species, as I have from the United States Coastal Plain, Mexico, Panama, and Colombia specimens which have not yet been sufficiently studied.

The loosely coiled species, typical *Operculina*, range from Middle Eocene to Miocene in America; the involute species range from Middle Eocene to the very high Oligocene, possibly Miocene (upper part of the Culebra formation).

HETEROSTEGINA

Cushman, 1919, described *Heterostegina antillea* from the Oligocene of Antigua, and in 1920*b* he described *H. ocalana* and a variety, *glabra*, from the Ocala limestone of Florida. A small undescribed species is abundant in the Culebra formation at Bohio Ridge Switch, Panama Canal Zone, and specimens are abundant in the Eocene and Oligocene limestones of Jamaica, but the Jamaican species have not been determined. The stratigraphic range of *Heterostegina* is from Upper Eocene to the Upper Oligocene (upper part of the Culebra formation). Some of the Eocene specimens have considerable resemblance to *H. depressa* d'Orbigny.

"ORTHOPHRAGMINA"

This name is invalid because the organisms to which Munier-Chalmas applied it had received several designations prior to his publication in 1891.

Montfort in 1808 used the name *Lycophris*, to which species of "Orthophragmina" were subsequently referred, but it appears to be a synonym of *Nummulites* Lamarck, 1801.

Schlotheim in 1822 proposed *Asteriacites* as a monotypic genus, of which *A. patellaris* is the type, but this name may have to be superseded by *Asteriatites*, 1813, also of Schlotheim.

Bronn, 1851-52, applied *Hymenocyclus* to orbitoidal foraminifera, and included in the genus *H. faujasi* (Defr.), *? H. mantelli* (Morton), and *H. papyracea* (Boubée). *H. faujasi* belongs to the genus *Orbitoides* of d'Orbigny, 1847; but, as *H. papyracea* (Boubée) is referred to *Simplorbites* de Gregorio (see H. Douvillé, 1921, pages 217 et seq.), *Simplor-*

bites would be a synonym of *Hymenocyclus*, and it seems that *Hymenocyclus* should be the generic name for *Nummulites papyracea* Boubée and *Orbitolites gensaicus* Leymerie, etcetera (see H. Douvillé, 1921, page 219).

In 1863 Schafhäutl proposed for *Asteriacites patellaris* Schlotheim the genus name *Asterodiscus*, which is clearly a synonym of *Asteriacites*. Furthermore, since the name *Asterodiscus* had been proposed by Ehrenberg in 1838 for a species designated by him as *Asterodiscus forskalii*, *Asterodiscus* Schafhäutl, 1861, is a homonym of *Asterodiscus* Ehrenberg, 1838, and for this other reason it is not available for *Asteriacites patellaris* Schlotheim.

Gümbel in 1868 published his classic memoir on *Orbitoides*. For the forms with rectangular meridional chambers he proposed four subgenera, as follows: (1) *Discocyclina*, (2) *Rhipidocyclina*, (3) *Aktinocyclina*, and (4) *Asterocyclina*. Numbers 1 and 2 are discoid forms, numbers 3 and 4 are stellate forms, and number 3 is a synonym of *Asteriacites* Schlotheim.[2]

In a brief statement, such as this necessarily is, an extensive review of literature is not practicable. The valuable memoir of Gümbel has been mentioned. The most important recent publication is one by H. Douvillé, 1922, in which references to earlier papers may be found. Those by Schlumberger are particularly noteworthy.

Douvillé in the paper cited adopts Gümbel's *Discocyclina* for the discoid species, rejecting *Rhipidocyclina*. He divides the radiate forms into *Asterodiscus*, attributing the name to Schafhäutl, forms which have only a small number of rays, usually 6, and *Aktinocyclina* of Gümbel, forms which have a larger number of rays, ordinarily more than 12. Douvillé places the *Asteriacites patellaris* of Schlotheim in *Aktinocyclina* of Gümbel, separating it from *Asterodiscus* of Schafhäutl.

Although I have not made a sufficiently exhaustive study of the literature on this group of foraminifera to settle the problem of its nomenclature, I shall apply the name *Discocyclina* to the discoid and lenticular forms and the name *Asteriacites* to the stellate forms.

The American species of "Orthophragmina" have been described principally by J. A. Cushman, 1920*a*, in a summary paper. The *Orthophragmina hayesi* of Cushman is a species of *Lepidocyclina* with rhomboid meridional chambers. H. Douvillé placed *Orthophragmina floridana* Cushman in a new genus, to which he applies the name *Pseudophrag-*

[2] For completion of bibliographic references, see C. D. Sherborn, Index to gen. and spec. foram. Smithson. Mis. Coll., 1893-96.

mina.[3] After eliminating the *Lepidocyclina hayesi,* I have prepared the following key to the described American species (pages 792, 793).

Besides the species above considered, I have in my possession three unpublished new species from eastern and northeastern Mexico, one from Jamaica, and one from Lower California.

In the Coastal Plain of the United States *Discocyclina* ranges from the lower Claibornian Saint Maurice formation of Louisiana to the upper Eocene Ocala limestone of Florida and Georgia. In Mexico *Discocyclina* is found in association with *Venericardia potapacoensis* in eastern Tamaulipas, at a horizon near the base of the Claiborne or in the upper Wilcox. In the State of San Luis Potosí *Discocyclina* is found in the Chicontepec formation below deposits of Claibornian age and in deposits of probably Wilcox or even Midway age. The genus ranges upward in Mexico, including Chiapas, to Middle and apparently Upper Eocene. *Discocyclina* occurs in general in the Eocene deposits of Central America, northern South America, and the West Indies. I have described, but not yet published, a new species from the Jamaican "Yellow limestone," which is either of lower Claiborne or upper Wilcox age. *Discocyclina* occurs normally in the Upper Eocene of the entire Caribbean region. *D. minima, D. cubensis, D. crassa, D. pustulata, D. marginata,* and *D. sculpturata* are species described by Cushman. A species the same as or very similar to *D. flintensis* is common in Chiapas and northern Columbia.

Asteriacites, under which I am including the few- and the many-rayed species, appears to be confined to the Upper Eocene, and thereby seems to differ from its occurrence in Europe, where it is also reported from the Lutetian.

Pseudophragmina occurs in the Upper Eocene Ocala limestone of Florida, where it is represented by *P. floridana* (Cushman) H. Douvillé.

The species above considered are inadequately described, because the embryonic chambers have not been studied. I hope that I may be able to supply this deficiency in information for the American species.

[3] Soc. géol. France, C. R. somm., May 28, 1923. Revision des Lépidocyclines. Soc. géol. France, n. s., vol. 1, mem. 2, 1924, p. 30.

KEY TO THE PUBLISHED AMERICAN SPECIES OF DISCOCYCLINA, ASTERIACITES, AND PSEUDOPHRAGMINA

Discocyclina

		Geologic horizon and locality
Test lenticular.		
Small, diameter 1.5 to 5 millimeters.		
With thinner peripheral portion.		
Thickness two-fifths the diameter	*D. minima*	Upper Eocene, Panama.
Thickness one-fifth diameter	*D. pustulata*	Upper Eocene, Cuba.
Without extended thinner peripheral portion.		
Thickness one-half the diameter	*D. cubensis*	Upper Eocene, Cuba, etcetera.
Thickness exceeds one-half the diameter	*D. crassa*	Upper Eocene, Cuba, etcetera.
Small, diameter 6 millimeters.		
With thinner peripheral portion, surface coarsely papillate	*D. peruviana*	Eocene, Peru.
Test distinctly umbonate.		
Large, diameter 12 to 14 millimeters		
With thinner peripheral portion.		
Thickness (?) the diameter.		
Surface granulate	*D. marginata*	Upper Eocene, Saint Bartholomew.
Test almost flat, slightly umbonate.		
Medium-sized, diameter 3.7 to 7 millimeters.		
Thickness (?) the diameter.		
Surface granulate	*D. clarki*	Middle Eocene, California, and Mexico.
Small, diameter 5 millimeters.		
Surface slightly pustulate	*D. flintensis*	Upper Eocene, Georgia, and Florida.
Test with thin central area.		
Medium-sized, diameter 5 to 7 millimeters.		
Surface slightly granular	*D. advena*	Middle Eocene, Louisiana.

Test sellaeform.

Test sellaeform.
Medium-sized, diameter 5 to 7 millimeters.
With thinner peripheral portion.
Thickness two-sevenths the diameter.
Center papillate, reticulate between papillæ.....*D. sculpturata*.....Upper Eocene, Cuba.

Geologic horizon and locality

Asteriacites

Test small, diameter 1.5 to 2 millimeters.
Usually with 5 arms.....*A. subtaramelli*...Upper Eocene, Cuba.
Test medium-sized.
Quadrangular.
Diameter about 6 millimeters.
Interradial areas between the four arms flat.....[4]*A. georgiana*.....Upper Eocene, Georgia, Florida, and West Indies.
Diameter 5 to 10 millimeters.
Interradial area, with "U"-shaped depression separating the rays from more distal tumid portion.....*A. vaughani*.....Upper Eocene, Florida and Georgia.
Test large.
Octagonal.
Diameter about 12 millimeters.....*A. antillea*.....Upper Eocene, Saint Bartholomew.
Diameter, 15 to 16 millimeters.....*A. mariannensis*... Upper Eocene, Florida.
Ribs as many as twenty.
Diameter up to 25 millimeters.....*A. americana*.....Upper Eocene, Florida and Georgia.

Pseudophragmina

Test discoid.
Test rather large, diameter 10 to 14 millimeters
Surface papillate.....*P. floridana*.....Upper Eocene, Florida and Georgia.

[4] H. Douvillé, 1924, considers this the same as *Creseis asterodiscus* R. J. L. Guppy.

Lepidocyclina and its Allies

General statement

For the general treatment of this group of foraminifera reference is made to papers by Lemoine and R. Douvillé (1904), H. Douvillé (1924), J. A. Cushman (1920*a*), and T. W. Vaughan (1923*a*). Although H. Douvillé did not initiate the critical study of the embryonic and meridional chambers of this group of foraminifera, he has done more research on these features of the group than anyone else. He recognized in *Orbitoides* and *Lepidocyclina* five types of embryonic chambers, as follows: (1) Quadrilocular chambers, as in *Orbitoides* s. s.—for example, *O. media* (d'Archiac); (2) One large chamber with several smaller ones around it, *Pliolepidina,* type *P. tobleri* H. Douvillé; (3) Two subequal chambers, *Lepidocyclina* s. s., to which the nomenclatorially invalid subgeneric name *Isolepidina* is applied, type *L. mantelli* (Morton); (4) One large chamber partially embracing a smaller chamber, *Nephrolepidina,* type *L. marginata* (Micht); and (5) One larger chamber almost completely enveloping a smaller one, *Eulepidina,* type *L. dilatata* (Micht).

It appears to me that a sixth type will have to be recognized. In this type there are three or four, or even five, subequal embryonic chambers, one or two of which are somewhat larger than the others. In a number of specimens two chambers are somewhat larger than two others, the four chambers arranged as a cross. I propose for this type the name *Polylepidina* and designate as its type *Polylepidina chiapasensis* Vaughan, n. sp., described in the last part of this paper. In a previous paper (1923*a*) I considered this type of embryonic chamber as included under H. Douvillé's *Pliolepidina,* but I now think that it is distinct.

I have available for study sections of a species of *Orbitoides* from northern India, apparently *O. media* (d'Archiac) (plate 30, figure 4). It would lead too far afield to discuss in detail the embryonic chambers of this species, but it is pertinent to say that they are strikingly different from those of any American species of Lepidocycline foraminifera I have studied. I will add that the embryonic chambers of the American species seem different from those of *Lepidorbitoides* of Silvestri.

I am, therefore, recognizing five types of embryonic chambers among the American Lepidocyclines: (1) *Polylepidina,* (2) *Pliolepidina,* (3) *Lepidocyclina,* s. s., (4) *Nephrolepidina,* and (5) *Eulepidina.* Whether these subdivisions should be accorded generic or subgeneric rank is not quite clear. All of the types can be derived from the *Polylepidina,* which appears to be the oldest stratigraphically. *L. macdonaldi* is intermediate between *Nephrolepidina* and *Lepidocyclina,* s. s. The forms included under *Lepidocyclina,* s. s., probably will ultimately be subdivided, because

the embryonic chambers of *L. mantelli* and *L. supera* are not quite like those of *L. canellei* and *L. miraflorensis*. *Nephrolepidina* and *Eulepidina* grade into each other. *L.* (*Nephrolepidina*) *undosa* Cushman shows such intergradation. Under the circumstances it appears preferable to consider the subdivisions of subgeneric rank.

The meridional chambers of the American Lepidocyclines fall into two larger categories, namely, (1) those whose chambers are arranged in intersecting outwardly convex curves, and (2) those that do not exhibit arrangement in such curves, but are more or less distinctly radial.

MERIDIONAL CHAMBERS IN INTERSECTING CURVES

General statement as to type.—The meridional chambers of the first category present at least four principal types, as follows: (1) The outer, distal, wall is outwardly convex, and the lateral walls either converge and meet at a point (the ogival form) or they do not meet, in which case the proximal boundary of the chamber is truncate and is formed by the wall of a chamber in the next inner cycle of chambers. This is the type of chamber designated by H. Douvillé "lozangique," lozenge-shaped. In this type either the radial or tangential diameter may be the longer. In *L. macdonaldi* Cushman in some chambers the radial diameter exceeds the tangential. In all the species of *Polylepidina* examined by me—*P. chiapasensis, P. adkinsi,* and *P. proteiformis*—the tangential usually exceeds the radial diameter. (2) Definitely hexagonal chambers, such as those of *L. mantelli, L. canellei,* and many other species. Hexagonal chambers may differ in the ratios of the tangential to the radial diameter. The two diameters may be equal, the radial may exceed the tangential in length, or the length of the tangential diameter may exceed that of the radial. (3) Intermediate between (2) and (3). One of the intermediate forms of chamber is the "spatulate" form of Verbeek (see Douvillé, 1924). In this form the radial diameter of the chamber exceeds the tangential, the proximal end of the chamber is acute, the lateral walls are parallel, and the distal wall is arcuate. *Lepidocyclina gigas* Cushman furnishes a typical example of this type of chamber. (4) Chambers quadrangular, nearly square, or rhomboid; one of the diagonals directed radially, the other tangentially. This type of chamber grades into the preceding types. It is a derivative from the "ogival" form of (1)—that is, from chambers with pointed inner ends and arcuate outer walls. In *L. vaughani* the length of the radial diameter of many chambers exceeds that of the tangential diameter. H. Douvillé has proposed the subgeneric name *Amphilepidina* for species with nephrolepidine embryonic chambers and spatulate meridional chambers. The type species is *Lepidocyclina chaperi* Lem. and R. Douv.

Polylepidina.—Meridional chambers, outer wall arcuate, inner end pointed or truncate, tangential usually exceeds radial diameter:

L. (*Polylepidina*) *chiapasensis* Vaughan,
n. sp. (plate 30, figures 1-3, text figure 4).....Eocene, Chiapas.

L. (*Polylepidina*) *adkinsi* Vaughan,
n. sp. (plate 31, text figure 5)....Eocene, Chiapas.

L. (*Polylepidina*) *proteiformis* Vaughan,
n. sp. (plate 32, text figure 6)....Eocene, Mecapala, Vera Cruz.

Pliolepidina.—Meridional chambers lozenge-shaped to square:

L.[5] (*Pliolepidina*) *tobleri* H. Douvillé..Eocene, Trinidad.

Meridional chambers lozenge-shaped, inner ends pointed to rhomboid:

L. (*Pliolepidina*) *duplicata* Cushman[6],
(plate 33, figure 2).....Eocene, Panama.

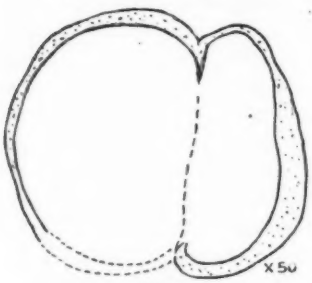

Fig. 1

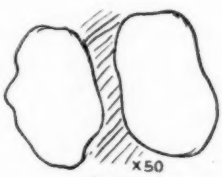

Fig. 2

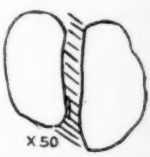

Fig. 3

FIGURE 1.—*Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton)

Specimen from U. S. Geological Survey station 5619, Vicksburgian Oligocene, Lovetts Creek, 2 miles west of Nero, Monroe County, Alabama. Collected by G. C. Matson. Camera lucida tracing of the embryonic chambers, × 50.

FIGURE 2.—*Lepidocyclina* (*Lepidocyclina*) *ocalana* Cushman

Topotype from U. S. Geological Survey station 6804, upper Eocene Ocala limestone, quarry number 1 of the Florida Lime Company, Ocala, Florida. Collected by C. W. Cooke. Camera lucida tracing of the embryonic chambers, × 50.

FIGURE 3.—*Lepidocyclina* (*Lepidocyclina*) *floridana* Cushman

Topotype from U. S. Geological Survey station 6805, upper Eocene Ocala limestone, Oakhurst Lime Company (plant number 2, Florida Lime Company), 2 miles southeast of Ocala, Florida. Collected by C. W. Cooke. Camera lucida tracing of the embryonic chambers, × 50.

[5] Probably synonymous.

[6] The specimens identified by Cushman from near David, Panama, locality 6523, U. S. Geological Survey regisfer, as *L. panamensis* are not *L. panamensis*, but are the macrospheric form of his *L. duplicata*. The following figures of Cushman, 1918*b*, represent *L. duplicata:* Plate 39, figures 1, 2, 3, and 5 (these specimens are not from Tonosi, station 6586*e*, as stated in the plate explanation, but are from 6523, near David), and plate 42, specimen with elongate embryonic chambers as seen in section.

Meridional chambers hexagonal to rhomboid:

L.[2] (*Pliolepidina*) *panamensis* Cushman, (plate 33, figure 1)..... Oligocene? Panama.

Lepidocyclina, s. s.—Meridional chambers of intermediate type:

L. (*Lepidocyclina*) *mortoni* Cushman, (plate 36, figures 1-3)..... Eocene, Louisiana.

L. (*Lepidocyclina*) *ocalana* Cushman (text figure 2)..... Eocene, Florida.

L. (*Lepidocyclina*) *floridana* Cushman text figure 3)..... Eocene, Florida.

L. (*Lepidocyclina*) *subraulini* Cushman ..... Eocene, Cuba.

L. (*Lepidocyclina*) *macdonaldi* Cushman ..... Eocene, Panama.

Meridional chambers lozenge-shaped, pointed inner ends:

L. (*Lepidocyclina*) *giraudi* R. Douvillé ..... Oligocene?, Martinique.

Meridional chambers lozenge-shaped to square:

L. (*Lepidocyclina*) *trinitatis* H. Douvillé ..... Eocene, Trinidad.

L. (*Lepidocyclina*) *pustulosa* H. Douvillé ..... Eocene, Trinidad.

Meridional chambers hexagonal or more or less spatulate:

L. (*Lepidocyclina*) *mantelli* (Morton) (text figure 1)..... Lower Oligocene, Mississippi, Alabama, and Florida.

L. (*Lepidocyclina*) *supera* (Conrad) (plate 33, figure 3)..... Upper Oligocene, Mississippi.

L. (*Lepidocyclina*) *miraflorensis* Vaughan ..... Upper Oligocene, Panama.

L. (*Lepidocyclina*) *parvula* Cushman.. Upper Oligocene, Antigua.

L. (*Lepidocyclina*) *canellei* Lem. and R. Douv. (plate 33, figure 4)..... Upper Oligocene, Panama and West Indies.

Meridional chambers hexagonal to square:

L. (*Lepidocyclina*) *r. douvillei* Lisson[1]. Eocene, Peru.

Nephrolepidina.—Meridional chambers of intermediate type:

L. (*Nephrolepidina*) *perundosa* Cushman ..... Eocene, Cuba.

Meridional chambers lozenge-shaped:

L. (*Nephrolepidina*) *decorata* H. Douvillé ..... Oligocene?, Haut Chagres, Panama.

[1] *L. peruviana* Cushman, 1922, is a synonym of this.

Meridional chambers hexagonal to spatulate:

L. (*Nephrolepidina*) *fragilis* Cushman (plate 33, figure 5).....Upper Eocene, Florida.

L. (*Nephrolepidina*) *undosa* Cushman (plate 34, figures 5-7).....Middle Oligocene, Antigua, Mexico, etc.

Meridional partly or mostly hexagonal:

L.[8] (*Nephrolepidina*) *marginata* (Micht), ident. Cushman and H. Douvillé (plate 34, figure 1).....Oligocene, Cuba, Mexico, Trinidad.

L.[9] (*Nephrolepidina*) *crassata* Cushman (plate 34, figures 3-4).....Oligocene, Cuba, Mexico, etc.

L.[8] (*Nephrolepidina*) *chattahoocheensis* (plate 34, figure 2).....Middle Oligocene, Georgia, Mexico.

L.[9] (*Nephrolepidina*) *schlumbergeri* Lem. and R. Douvillé t. Cushman.Oligocene, Cuba.

L. (*Nephrolepidina*) *tournoueri* Lem. and R. Douvillé (plate 33, figures 6, 7).....Oligocene, Mexico; also Trinidad.

L. (*Nephrolepidina*) *morgani* Lem. and R. Douvillé t. Cushman.....Oligocene, Cuba, Mexico.

L.[10] (*Nephrolepidina*) *sumatrensis* (Brady) t. Cushman.....Oligocene, Cuba.

Meridional chambers hexagonal to rhomboid:

L. (*Nephrolepidina*) *yurnagunensis* Cushman (plate 33, figure 8).....Oligocene, Cuba.

Meridional chambers rhomboid:

L. (*Nephrolepidina*) *vaughani* Cushman (plate 33, figure 9).....Upper Oligocene, Panama, Antigua.

Amphilepidina.—Meridional chambers spatuliform (*Amphilepidina* of H. Douvillé):

L.[11] (*Amphilepidina*) *chaperi* Lem. and R. Douvillé.....Oligocene?, Haut Chagres, Panama.

L. (*Amphilepidina*) *persimilis* H. Douvillé .....Oligocene?, Trinidad.

L. (*Amphilepidina*) *predilatata* H. Douvillé .....Upper Eocene, Trinidad.

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[8] These three forms are very similar and all may be variants of the same species.

[9] Cushman may have included more than one species under this name. The specimens from one locality are very similar to *L. elephantina* Munier-Chalmas.

[10] I am convinced that the specimens from Cuba referred by Cushman to *L. sumatrensis* are incorrectly identified, and I believe that they belong to the same species as specimens I am referring to *L. tournoueri*. Additional sections of the Cuban material are needed in order to settle this point.

[11] The *L. chaperi* of Cushman, 1918, from the Panama Canal Zone is not *L. chaperi* Lem. and R. Douv. *L. undosa* Cushman is probably a synonym of *L. chaperi* Lem. and R. Douv.

Eulepidina.—Meridional chambers radially short hexagonal or short spatulate:

L. (*Eulepidina*) *favosa* Cushman (plate 34, figure 8).....Middle Oligocene, Antigua.

Meridional chambers spatulate, longer than in the preceding:

L. (*Eulepidina*) *dilatata* (Micht) t. H. Douvillé .....Oligocene, Trinidad.

L. (*Eulepidina*) *raulini* Lem. and R. Douvillé t. H. Douvillé.....Oligocene, Trinidad.

L.[12] (*Eulepidina*) *formosa* Schlumberger .....Oligocene, Trinidad, Panama, Mexico.

Species on which information is deficient.—Cushman based on microspheric forms several species the macrospheric forms of which have not yet been certainly recognized, and of a few other species there are not enough specimens for making the necessary sections. They are as follows:

Microspheric forms:

L. attenuata Cushman.—This is a synonym of *L. ocalana* var. *subdecorata* Cushman. *L. ocalana* has isolepidine embryonic chambers. Upper Eocene, Florida.

L. georgiana Cushman.—The specimens from locality 7194, U. S. Geological Survey register, at Marianna, Florida, are the microspheric form of *L.* (*Nephrolepidina*) *fragilis* Cushman. Specimens referred to *L. georgiana* by H. Douvillé, 1924, have, according to him, isolepidine embryonic chambers. Upper Eocene, Georgia, Florida.

L. gigas Cushman.—This is a microspheric form which appears to belong to the same species as *L. undosa* Cushman. The two forms invariably occur together. This is true in Antigua, Mexico, and Jamaica, and the structure is similar. *L. undosa* is usually more saddle-shaped than *L. gigas,* but this is not always the case. The meridional chambers of *L. gigas* are spatulate, as are also those of *L. undosa.*

L. undulata Cushman.—This species is also based on microspheric specimens. It is so very similar to *L. gigas* that I have inclined to consider them synonymous. They are alike in size, form, and surface features, and the meridional chambers of both are spatulate and of similar size. The lateral chambers in typical *L. undulata* are a little longer (radially) and a little higher (vertically), but these differences appear

[12] Mr. W. S. Adkins, of the "Aguila" Petroleum Company, has brought me large numbers of a species of *Eulepidina* which is very similar to *L. favosa,* but is usually much more inflated. This seems to be the species designated *L.* (*Eulepidina*) *formosa* Schlumberger by H. Douvillé, 1924.

to be attributable to variation. The pillars are similar in both forms. The only reason for my hesitation to combine as one species *L. undosa*, *L. gigas*, and *L. undulata* is that there is associated with them a species with isolepidine embryonic chambers and I have not yet identified the microspheric form of it. The study of the Antiguan species of *Lepidocycline* is sill incomplete.

Material insufficient for sections:

L. cookei Cushman.....Upper Eocene, Florida.
L. pseudocarinata Cushman.....Upper Eocene, Florida.
L. pseudomarginata Cushman.....Eocene, Florida.
L. hayesi (Cushman) Vaughan.....? Upper Eocene, Nicaragua.

(NOTE.—Since sending the manuscript of this article to press, I have received a large lot of material from the Oakhurst plant of the Florida Lime Company, Ocala, Florida, collected for me through the kind offices of Mr. Herman Gunter, State Geologist of Florida. I have obtained from this material both macrospheric and microspheric specimens of *L. cookei*, *L. pseudocarinata*, and *L. pseudomarginata*, and I made sections to expose the embryonic chambers of each of the three species. All three species have isolepidine embryonic chambers similar to those of *L. ocalana*.)

This species has rhomboid meridional chambers and resembles *L. panamensis* Cushman, but I have not yet succeeded in discovering the nature of the embryonic chambers.

L. hilli Cushman.....? Oligocene, Costa Rica.

This species is based on a single specimen, probably one of the microspheric form.

L. chaperi Cushman, not Lem. and R. Douv., from the Panama Canal Zone, upper part of the Culebra formation .....Upper Oligocene.

Although a considerable number of specimens of this species were found in Gaillard cut, Canal Zone, the condition of preservation is not satisfactory and, consequently, the nature of the embryonic chambers is not disclosed.

MERIDIONAL CHAMBERS RADIALLY ARRANGED

There is only one species, *L. antillea* Cushman (plate 35) from the Upper Eocene of Saint Bartholomew, belonging to this group. I doubt if this species is *Lepidocyclina* at all. The outer wall of each meridional chamber is a flat arc which does not meet the outer walls of the adjacent chambers on each side, while the inner boundary of the chamber is formed by the outer wall of a chamber belonging to the next inner cycle

of chambers (plate 35, figures 1, 2). The tangential diameter is much longer than the radial diameter, as much as twice as long. In the microspheric form the initial part of the test is closely coiled (plate 35, figure 2). In some respects the chambers show considerable resemblance to *Omphalocyclus*. Plate 35, figures 1 and 2, illustrate horizontal sections; figure 3, a vertical section.

SUMMARY STATEMENT ON LEPIDOCYCLINE SPECIES

In the foregoing discussion 51 species or supposed species of *Lepidocyclina* have been considered. After critical revision has been completed it is probable that the number of specific names will be considerably reduced. I have gone over the total list of names and indicated those that it seems from present information are probably synonyms. According to this review, there are 39 valid species. There are many species from America which have not yet been published. I have in my possession specimens of the following species which are either new or not yet recorded from America:

Oligocene of Mississippi	2	
Oligocene of Florida	1	
Oligocene of Cuba	2	
Eocene of Mexico	2	
Oligocene of Antigua	1	
Eocene of Jamaica	5	
Eocene? of Jamaica	1	
Oligocene of Jamaica	2	(—1; also Mississippi)
Eocene? of Panama	1	
Eocene of Venezuela and Colombia, probably	2	
	19	

Although further study may cause me to withhold the naming of some of these forms, other species may be discovered. The total number of species of American Lepidocycline foraminifera may confidently be placed at over 60. Of the undescribed or not yet reported species I have worked out the embryonic and meridional chambers of all except two species. Regarding two of the undescribed species, it will be said that the unreported form from Florida is a small almost globular species of the aspect of *L. sumatrensis* (Brady). It occurs in the Glendon formation. One of the Cuban species is a stellate *Nephrolepidina*.

The stratigraphic distribution of the American species of the subgenera of *Lepidocyclina* is as follows:

	Upper Eocene	Oligocene		
		Lower	Middle	Upper
L. (Polylepidina)	x	....	....	....
L. (Lepidocyclina)	x	x	x	x
L. (Pliolepidina)	x	....	....	....
L. (Nephrolepidina)	x	x	x	x
L. (Eulepidina)	....	....	x	....

A part of what has heretofore been called Upper Oligocene in America is considered Miocene by many paleontologists.

Helicolepidina (Spiroclypeus)

Tobler (1922) has described a peculiar species of foraminifera from the Upper Eocene of Venezuela and Trinidad under the name *Helicolepidina spiralis*. Tobler considered his *Helicolepidina* as a subgenus of *Lepidocyclina*, but H. Douvillé (1923) is of the opinion that it belongs to a different genus, and refers it to *Spiroclypeus* (1924, page 21). I believe Douvillé is correct.

Miogypsina

The *Heterosteginoides* of Cushman (1918*b*) from the Panama Canal Zone is apparently a synonym of *Miogypsina* Sacco, 1887. There are at least two species of *Miogypsina* in the Panama Canal Zone and Cushman may have confused two species under his *Hesterosteginoides panamensis*, the type of which is from locality 6025, U. S. Geological Survey register, Bohio Ridge Switch, Panama Railroad, relocated line. Cushman (1918*b*) figures, plate 43, figures 3-8 (probably not figures 1, 2) this species. In it the embryonic chambers are situated well back from the periphery. They are two in number, subequal in size, the distance across the two chambers, 0.25 millimeter; greater diameter of a single chamber, 1.15 millimeters. The earlier meridional chambers are spiral in arrangement, but the arrangement soon becomes in intersecting curves. Plate 36, figure 7, of this paper illustrates a horizontal section. In the other species for which I propose the name *Miogypsina cushmani* Vaughan, n. sp., there are two apical equal embryonic chambers, which are succeeded by from one to three chambers which are intermediate in size between the embryonic and usual meridional chambers. The distance across the two embryonic chambers is 0.35 millimeter; greater diameter of a single chamber, 0.225 millimeter. Plate 36, figures 4-6, of this paper illustrate horizontal sections of *M. cushmani*. Plate 43, figures 1 and 2, Cushman, 1918*b*, seem to represent it and to illustrate its sur-

face features. The species is small, compressed, subtrigonal in shape, about 2 millimeters long and also about 2 millimeters in maximum width.

Cushman, 1919, described another species from material I collected in the Island of Anguilla and applied the name *Heterosteginoides antillea* to it.

The three species above noted all occur in deposits referred to high Oligocene or Lower Miocene—that is, the American equivalent of the European Aquitanian—but it is not entirely improbable that the beds carrying *M. cushmani* in the Panama Canal Zone and the beds carrying *M. antillea* in Anguilla are of Langhian (Burdigalian) age.[13]

That *Miogypsina* alone is not sufficient evidence for referring a bed to Upper Oligocene or Lower Miocene is shown by the numerous specimens of *Miogypsina* contained in material collected by Dr. C. A. Matley in the Montpelier white limestone of Jamaica, which is either of Lower Oligocene or Upper Eocene age. I wished to describe and publish figures of this species in the present paper, but must content myself with mentioning it.

Orbitoclypeus

A species, apparently belonging to this genus, has been found in deposits, apparently of Lower Eocene age, in a well at El Cristo, State of Vera Cruz, Mexico. A description of it is given on a subsequent page. *Orbitoclypeus* was described by Silvestri from the Eocene of Italy.

Dictyoconus

Three species belonging to or related to this genus have been described from the Tertiary deposits of America, as follows:

Conulites americana Cushman (1919), Upper Eocene, Saint Bartholomew.

Dictyoconus codon Woodring (1924), from the Middle Eocene Plaisance limestone of Haiti; also found in Jamaica.

Dictyoconus puilboreauensis Woodring (1924), from the Middle Eocene Plaisance limestone of Haiti. Woodring suggests that this may be the macrospheric form of *D. codon*.

Dictyoconus puilboreauensis var. *nannoides* Woodring (1924), from the Upper Eocene limestone of Haiti.

I have discussed the occurrence of *Dictyoconus* in Florida (Vaughan, 1923*a*), where it ranges upward into deposits referred by Cooke to the Middle Oligocene Glendon limestone. A species, apparently *D. codon* Woodring, was obtained from a deep well at Marathon, Florida. Dr.

[13] See C. W. Cooke: U. S. Geol. Survey Prof. Paper 129-B, 1921, p. 30, for *Orthaulax gabbi* in the Panama Canal Zone.

C. A. Matley obtained many specimens in Jamaica, where the genus is abundant in deposits of Middle and Upper Eocene age and seems to range into the Oligocene. *Dictyconus* appears to range higher in America than in Europe.

Orbitolites ?

Dr. C. A. Matley collected in the Middle or Lower Eocene of Jamaica great numbers of specimens of a genus of foraminifera with which I was hitherto entirely unfamiliar. The microspheric form produces thin flat disks which are as much as 50 millimeters in diameter. The growth form in the early stages is an involute, flat spiral which passes into a concentric growth form, the outer surface of the test being marked by raised concentric lines. The interior of the test exhibits a criscross or zigzag structure between the concentric lines. The macrospheric form resembles in its external features an *Operculina*, and until sections were made I mistook the specimens for *Operculina*. Between what at first appeared to be the chamber walls there is the criscross structure also seen in the microspheric specimens of concentric growth form. The embryonic chamber is a single, large, undivided chamber, which is succeeded by the operculinoid growth form above indicated. In vertical sections of the macrospheric form there are at least three layers of chambers, a median, with a lateral on each side. I have hastily compared the thin-sections with thin-sections of *Orbitolites complanatus*, *Sorites duplex?*, and *Orbiculina adunca*. Although I have not completed the study of the specimens, they seem to me to belong to a genus akin to *Orbitolites* and they possibly represent a section of that genus in which the structure is very complex.

Orbiculina, Sorites, and Peneroplis

Conrad in 1846 (see Sherborn, 1896) described from Tampa, Florida, a species to which he applied the name *Nummulites floridanus*. Fossils identified as this species are common in the Tampa formation of peninsular and western Florida and are usually referred to the genus *Orbitolites*.

Cushman, 1918*a*, lists *Peneroplis pertusus*, *Orbiculina adunca*, and *Orbitolites marginalis* from the Caloosahatchee Pliocene of Florida, and, 1918*b*, described *Orbitolites americana* from the Culebra formation of the Panama Canal Zone and listed it from the Emperador limestone. Cushman, 1919, reports *Peneroplis pertusus*, *Orbiculina adunca*, and *Orbitolites complanatus* from the Miocene (Cercado formation) of the Dominican Republic; *Orbiculina compressa* from the Miocene Bowden

marl of Jamaica, and *Orbitolites* (*Sorites*) *duplex* from the Miocene or uppermost Oligocene of Saint Martin, Anguilla, and Cuba. Vaughan, 1923*b*, on the basis of Cushman's identifications, reports *Orbitolites duplex?* or *Orbitolites* from the Upper Oligocene or Miocene of Saint Croix, Vieques, and eastern Porto Rico.

Dr. C. A. Matley has collected numerous specimens of *Orbiculina* and *Peneroplis* in the Upper Oligocene or Lower Miocene limestones of Jamaica and *Sorites* may be represented.

When perfectly preserved material is available for study, there is no great difficulty in distinguishing between specimens of *Orbiculina* with an early development of annuli and specimens of *Sorites,* but in fossil specimens it is often not practicable to be certain regarding the early stages. I wished to restudy all the American material reported as *Orbitolites* or *Sorites* and incorporate the results in this review, but I have not been able to make the necessary examinations in the time available.

Peneroplis and *Orbiculina* of both the *O. adunca* and *O. compressa* facies may be disposed of by stating that they certainly range from Miocene to Recent. A number of the specimens reported as *Sorites duplex* seem to me to be *Orbiculina* of the *O. compressa* growth form, but not that species. I think there are two species of *Orbiculina* at locality 3446, U. S. Geological Survey register, near La Cruz, Cuba. These are referred by Cushman, 1919, to *Orbitolites* (*Sorites*) *duplex.*

Douvillé, 1924, says regarding Cushman's *Orbitolites americana* that it is a rather abundant species in the Antilles, and that he has identified it with his *Orb. martini* from Sumatra. Douvillé refers his *Orbitolites martini* to *Sorites,* and consequently would place Cushman's *O. americana* in the same genus or subgenus. This species is very abundant in Jamaica. *Sorites,* therefore, appears to range in America from Upper Oligocene to Recent.

Alveolina

The genus *Alveolina,* including *Flosculina,* is very abundant in the Eocene limestones of Jamaica, where it is associated with *Dictyoconus, Lepidocyclina, Discocyclina,* and the peculiar genus of foraminifera I am tentatively referring to as *Orbitolites?.* A small species known as *A. pulchra* d'Orbigny, of which *A. melo* (Fichtel and Moll) may be a synonym, still lives in the tropical waters of America (Cushman, 1922*a*).

Conclusions

In general there is similarity between the stratigraphic distribution of the larger foraminifera in America and Europe, but there are some important differences.

In America there are few or no large *Nummulites,* but small nummulitoids range from the Eocene to the Oligocene.

Operculina in America ranges from the Middle Eocene to the Miocene.

Heterostegina ranges from the Upper Eocene to the Upper Oligocene.

Discocyclina ranges from Lower Eocene to Upper Eocene, but has not yet been found in the Upper Cretaceous, as in Europe.

Asteriacites is confined to the Upper Eocene, not yet having been found at a horizon so low as the Lutetian, as in Europe.

Pseudophragmina occurs in the Upper Eocene.

Lepidocyclina and its allies range from Upper Eocene to Upper Oligocene. The stratigraphic ranges of the different subgenera are given in tabular form at the end of the discussion of the species.

Helicolepidina (*Spiroclypeus*) is known only from the upper Eocene.

Miogypsina occurs perhaps in the Upper Eocene and is abundant in the Upper Oligocene. Some of the beds in which it occurs are probably referable to the Langhian.

A species doubtfully referred to *Orbitoclypeus* is here reported from beds of apparently Lower Eocene age. This genus occurs in the Eocene of Italy.

Dictyoconus is found in beds of Middle and Upper Eocene age, and apparently it ranges as high stratigraphically as Middle Oligocene, higher than in Europe.

Orbitolites? is here reported from Jamaica in beds of Lower or Middle Eocene age. This is a queer organism, which will later be described in detail.

Orbiculina and *Peneroplis* are common in deposits of Miocene and later age. *Sorites* appears to range from Upper Oligocene to Recent, but the discrimination between *Sorites* and *Orbiculina* with annular growth form is not certain.

Alveolina is very abundant in the Eocene rocks of Jamaica; a small species is still living.

The total number of American species belonging to the genera above considered is about 120. Many of the species are of great value in solving problems in stratigraphy, and it is hoped that they may soon be far better known than they are at present, both for geologic and biologic reasons.

Descriptions of new Forms

The following are descriptions of a few of the more significant new forms:

GENUS *LEPIDOCYCLINA* GUMBEL

Subgenus Polylepidina Vaughan, new subgenus.—The diagnostic features of *Polylepidina* are its embryonic apparatus, which consists of several chambers, four to five in number, of which one or two are larger than the others. In some specimens there are two subequal chambers somewhat larger than two other subequal chambers, the four chambers so arranged as to form a cross, the two larger chambers along the longer axis and the two smaller chambers along the shorter axis.

In the three species referred to *Polylepidina* the meridional chambers all have arcuate outer walls and many have pointed proximal ends, but

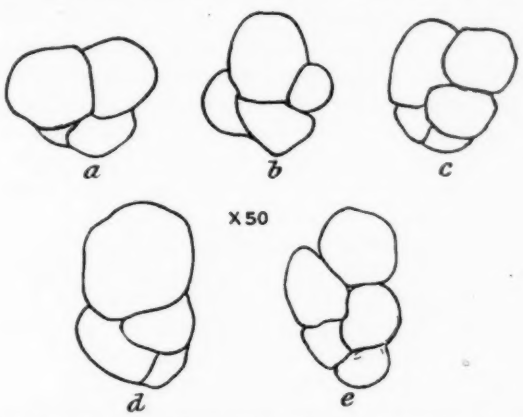

FIGURE 4.—*Lepidocyclina (Polylepidina) chiapasensis* Vaughan, new species

Cotypes from type locality of the species. Camera lucida tracings of the embryonic chambers of five specimens, × 50. Figure 5*c* is from a specimen represented by plate 30, figure 3. The other chambers traced are not shown on plate 30.

the inner ends may be truncate. The length of the tangential diameter exceeds that of the radial diameter.

Type species.—*Lepidocyclina (Polylepidina) chiapasensis* Vaughan, n. sp.

Polylepidina has meridional chambers somewhat like those of *Lepidorbitoides* Silvestri, but the method of communication between the chambers is different, according to the account of *Lepidorbitoides* as given by H. Douvillé (1921). The embryonic chambers are very different, those of *Lepidorbitoides* consisting of two chambers, one larger and partly embracing a smaller chamber. The chambers are decidedly different from those of *Orbitoides,* which has a quadrilocular embryonic apparatus

surrounded by a common thick wall. (See plate 30, figure 4, for an illustration of *O. media* (d'Archiac).)

Lepidocyclina (*Polylepidina*) *chiapasensis Vaughan, new species* (plate 30, figures 1, 2, 3).—Test small; compressed lenticular. Macrospheric form, 3.5 to 4 millimeters in diameter; 0.6 to 0.75 thick through the center. On the central part of the test there are small papillæ, about 0 10 millimeter in diameter, somewhat irregular in arrangement, distance apart about the same as the diameter. Outside the central part there is a relatively wide edge, 1 millimeter or somewhat more in width in larger specimens, composed entirely of meridional chambers, with no covering of lateral chambers. In some specimens there is a decidedly scant development of lateral chambers.

The embryonic apparatus consists of four or five larger chambers, around which are the smaller, usual meridional, chambers. Two or three of the chambers are larger than the others and are of subequal size. As seen in section, the embryonic chambers of some specimens seem to be on a plan of 4. The horizontal diameter of the embryonic apparatus ranges from about 0.4 to 0.45 millimeter; the vertical height is from 0.25 to 0.30 millimeter.

The meridional chambers have distally arcuate walls; the inner end is usually truncate; the lateral walls do not meet proximally, but their inner ends are separated by a segment of the distal wall of the next inner cycle of chambers. The communication between chambers is very distinct. Between 1 and 1.5 millimeters from the center of the test, the tangential diameter of the chambers ranges from about 0.125 to 0.15 millimeter and the radial diameter ranges from 0.05 to 0.1 millimeter. The tangential diameter is uniformly greater than the radial. In vertical section the height of the chambers near the center is about 0.15 millimeter; 1.5 millimeters from the center the height is 0.25 millimeter; in large specimens the height at the edge may be as much as 0.53 millimeter. This feature constitutes a striking difference from *L. proteiformis*, which in some respects is a similar species. The increase in the radial diameter of the chambers toward the periphery is not pronounced.

The lateral chambers in general are not greatly developed. Their absence near the periphery of the test has already been noted. Over the central part of the test there may be three or four layers. The chambers are irregular in size and shape, the floors and roofs thick, with small chamber cavities. Some of the vertical walls develop into the papillæ above noted, which rise from pointed inner ends. The lateral chambers are very well illustrated by the figures, plate 30, figures 2, 3.

Locality: M. 23 M. F. N., Chiapas, Mexico, 3.75 kilometers south and 6.25 kilometers east of Chilon. Collected by Mr. M. F. Nesbit.

Geologic horizon: Eocene.

Cotypes: U. S. National Museum.

Lepidocyclina (*Polylepidina*) *adkinsi Vaughan, new species* (plate 31, figures 1-5).—Test small to medium-sized, compressed lenticular. Microspheric form about 8.5 millimeters in diameter and about 1.8 millimeters thick through the center; macrospheric form 3.5 millimeters in diameter and about 0.6 millimeter thick through the center. Over the central part of test of the microspheric form there are numerous papillæ, 0.05 to 0.10 millimeter in diameter, distance apart usually equal to or somewhat greater than the diameter. The pillars, which the papillæ terminate, will be described later. The papillæ of the macrospheric form are similar to those of the microspheric, but smaller. Although the test becomes thinner toward the margin, the lateral chambers extend to the

FIGURE 5.—*Lepidocyclina* (*Polylepidina*) *adkinsi* Vaughan, new species

Cotype from type locality of the species. Camera lucida tracing of the embryonic chambers of a specimen, × 50.

periphery, and therefore there is no thin marginal zone entirely composed of meridional chambers, as in *L. proteiformis* and *L. chiapasensis*.

The embryonic chambers consist of two larger subequal chambers and there are usually two additional chambers of smaller size, the four chambers of 4-leaf clover aspect (see text figure 5). The chambers are similar to those of *L. proteiformis*. The horizontal diameter across the larger chambers is from 0.4 to 0.5 millimeter; the vertical diameter is between 0.30 and 0.25 millimeter.

(NOTE.—Subsequent to sending the manuscript of this paper to the editor I have received an additional set of thin-sections of *L. adkinsi*, made for me by the U. S. Geological Survey, and these have enabled me to make a more detailed study of the embryonic chambers of the species. In some specimens the two larger chambers far exceed in size the smaller chambers, and produce an embryonic apparatus of isolepidine appearance, but the accessory chambers as shown in text-figure 5 are represented. The transition to the type of embryonic chambers possessed by *L. supera* (see plate 33, figure 3) is complete.)

The meridional chambers gradually increase in size from the center toward the periphery. They present three shapes in the horizontal plane: (1) outer wall curved, inner end acute; (2) neatly diamond-shaped, the longer diagonal of the diamond lying in a tangential plane; (3) inner end truncate, the lateral walls of the chamber failing to meet at the inner end of the chamber. Shapes 1 and 3 are the commoner. In a microspheric specimen, about 1 millimeter from the center the tangential diameter of a chamber is about 0.125 millimeter, radial diameter about 0.075 millimeter; about 2 millimeters from the center, tangential diameter about 0.15 millimeter, radial diameter 1.10 millimeters; at the periphery, about 4 millimeters from the center, tangential diameter as much as 0.20 millimeter, but usually less; radial diameter about 0.10 millimeter. The tangential diameter is uniformly longer than the radial. Although the communication between chambers is distinct in much of the areas of the horizontal sections, parts of the sections show at the corners of many chambers thickenings which pass into pillars, and these emerge on the surface as papillæ. The vertical height of the meridional chambers increases from the center toward the periphery. Height at the center in the microspheric form, 0.05 millimeter; about 3.8 millimeters from the center, 0.30 millimeter; in the macrospheric form the height at the periphery is from 0.15 to 0.25 millimeter.

The lateral chambers are irregular in size and shape, but their length is usually several times the height, with irregularly thicker and thinner floors and roofs, as shown in the illustrations. In the microspheric form there are from 10 to 12 layers of chambers. One of the characteristic features of the vertical sections is the pillars, many, if not all, of which originate at the meridional chambers; they soon attain a considerable thickness, 0.05 to 0.10 millimeter, and maintain it to the outer surface.

Locality: M. 13 M. F. N., 2.75 kilometers south of Hacienda "El Triunfo," Chiapas, Mexico. Collected by M. F. Nesbit.

Geologic horizon: Upper Eocene.

Cotypes and paratypes: U. S. National Museum.

Relations: *L. adkinsi* belongs in the same group of species as *L. proteiformis* and *L. chiapasensis*, since all three species possess embryonic and meridional chambers of similar types. *L. adkinsi* differs from *L. proteiformis* by being thicker and possessing the pillars and corresponding surface papillæ above described. It differs from *L. chiapasensis* by its pillars and narrow thin margin.

Lepidocyclina (Polylepidina) proteiformis Vaughan, new species (plate 32, figures 1-7).—Test small to medium-sized; thin, very compressed lenticular. Diameter of fully grown macrospheric specimens 3.5

millimeters; thickness through the center about 0.6 millimeter or even a little less. Diameter of microspheric form, 6.5 to 7 millimeters; thickness through the center, about 0.75 millimeter. On the surface of the central part of the test there are usually small papillæ, which are irregular in cross section, but range in diameter from 0.05 millimeter to 0.17 millimeter; the range in distance apart is about the same as the diameter; radiating projections connect some adjacent papillæ. On some specimens the papillæ are absent or only slightly developed. The meridional chambers project somewhat beyond the lateral chambers and form a thin edge as much as 1 millimeter wide.

The embryonic chambers do not definitely fall into any one of the categories hitherto commonly recognized in the orbitoid foraminifera. There are two prominent chambers, one of which is somewhat larger than the other. In some specimens these chambers are of isolepidine aspect,

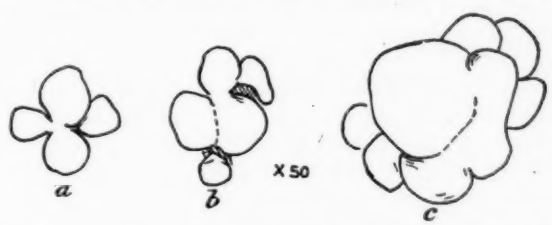

FIGURE 6.—*Lepidocyclina* (*Polylepidina*) *proteiformis* Vaughan, new species

Cotypes from type locality of the species. Camera lucida tracings of the embryonic chambers of three specimens, × 50. In figures 6*a* and 6*b* the tops of the chambers have been exposed and they exhibit a quadrilocular condition. Figure 5*c* is a tracing of the chambers of the specimen represented by plate 32, figure 4.

but they are not typically isolepidine, because one of them, in conjunction with other chambers, may form part of an indistinct spiral. Several specimens have embryonic chambers on a plan of four, so arranged that in plan they resemble a four-leaf clover. The indefiniteness, with variation from a bilocular to a quadilocular condition and passage into an indistinct spiral or cycle, seems characteristic of the embryonic chambers (see text figure 6). Because of the indefiniteness of the features, a number of camera-lucida sketches have been made, but all of them can not be published now. The horizontal diameter of the embryonic apparatus is about 0.5 to 0.7 millimeter; the vertical height is about 0.35 millimeter.

The meridional chambers are usually arcuate distally and pointed proximally; some are rhomboid, and a few have the proximal end truncate. Their shape is similar to that of *Orbitoides* s. s. Their size varies

considerably; they may be of subequal from near the embryonic chambers to the periphery, or the more peripheral chambers may be considerably larger than those near the center. In a specimen in which there is no pronounced difference between the more interior and more exterior chambers, the size in the horizontal plane ranges from 0.125 millimeter tangential and 0.09 millimeter radial diameter to 0.2 millimeter tangential and 0.13 millimeter radial diameter. The tangential diameter is uniformly greater than the radial. In a specimen in which the more peripheral chambers are larger than those nearer the center, the size of the proximal chambers is about 0.125 millimeter in tangential and 0.08 in radial diameter; that of the more distal chambers as much as 0.2 millimeter in tangential and 0.125 millimeter in radial diameter. Communication at the proximal end of the wall between adjacent chambers is distinct in many chambers. In vertical section the height of the meridional chambers near the center is about the same as the radial diameter, each being about 0.10 millimeter, but near the periphery the height may be as much as 0.18 millimeter, with a radial diameter of 0.125 millimeter. The pores in the walls between the meridional chambers are not distinct in the vertical sections, perhaps because of recrystallization of the material composing the test, but one horizontal section shows that the floors and roofs of the chambers are very minutely cribriform, and in one vertical section there seem to be cribriform perforations in the walls between the chambers.

In the central part of the test there are three or four layers of lateral chambers, the number of layers decreasing toward the periphery, with no lateral chambers over the meridional chambers near the edge. The lateral chambers are not uniform in size or regular in arrangement. In general the height of the chambers is about the same as the thickness of the walls between successive layers. In the smaller, macrospheric, form the length ranges from 0.10 millimeter to 0.30 millimeter; height, 0.04 to 0.06 millimeter; the length is usually several times the height. There are no definite tiers of lateral chambers, but the vertical walls between chambers may be thickened and produce on the surface papillæ, such as have already been described.

Locality: M. 118 V., Mecapala Hills, about 0.5 kilometer southwest of Palma Sola, Mecapala Hills, Vera Cruz, Mexico. Collected by T. W. Vaughan and D. R. Semmes. Also at other localities near by.

Geologic horizon: Eocene, associated with *Vencricardia planicosta* (Lam.). Whether the horizon is Upper (Jacksonian) or Middle (Claibornian) Eocene was not definitely ascertained.

Cotypes and paratypes: U. S. National Museum.

GENUS *MIOGYPSINA* SACCO

Miogypsina cushmani Vaughan, new species (plate 36, figures 4-6); (*Heterosteginoides panamensis Cushman, 1918b, pars*).—It was pointed out in discussing the American species of *Miogypsina* that it seems that Cushman confused two species under his *Heterosteginoides panamensis,* and that to one of these species I am applying the name *Miogypsina cushmani.* The following is a description of it:

Test small, compressed, subtrigonal in outline. Length of macrospheric form, about 2 millimeters; maximum width, about 2 millimeters; thickness, about 0.7 millimeter. Surface minutely papillate.

Two equal embryonic chambers, apically situated. These chambers are succeeded by from one to three chambers intermediate in size between the embryonic and the usual meridional chambers. Distance across the two embryonic chambers, 0.35 millimeter; greater diameter of a single chamber, 0.225 millimeter.

The meridional chambers are quadrilateral, diamond-shaped; longer diameter of the diamond from 0.2 to 0.24 millimeter; the shorter diameter, about 0.16 millimeter. Plate 36, figure 6, shows the nature of the perforations in the roofs and floors of the chambers.

Locality: Panama Canal Zone, at U. S. Geological Survey locality 6011 and 6012*d,* type and paratypes from 6012*d.*

Geologic horizon: Upper part of the Culebra formation, uppermost Oligocene, possibly Lower Miocene.

Cotypes: U. S. National Museum.

Relations: The relations of this species to *Miogypsina panamensis* (Cushman) have been discussed on page 802 of this paper and the notes there given need not be repeated here.

GENUS *ORBITOCLYPEUS* SILVESTRI

General statement.—The paper in which Silvestri (1907*a*) originally described this genus from the Eocene of Palermo is not accessible to me at the present time. I am, therefore, depending on a later published figure for the generic identification of the species next to be described (Silvestri, 1924). The figure I am using is of one of the original species, *Orbitoclypeus tellinii* Silvestri (Silvestri, 1907*b*). The form, size, and arrangement of the meridional chambers of *Orbitoclypeus cristensis* Vaughan, n. sp., are the same as in *O. tellinii,* but I can not be sure that the embryonic chambers are the same. The Mexican species is described here because it appears to show another analogy between the Eocene of tropical America and that of Italy.

Orbitoclypeus? cristensis Vaughan, new species (plate 36, figure 8).—The following description is based on a single specimen which has been incompletely sectioned in the horizontal plane:

Test small, discoid. Macrospheric form, 2 millimeters in diameter; thickness not known, but the test is obviously thin and wafer-like. Surface of test reticulate, apparently without papillæ; if papillæ should be present they are very small. A similar section of a specimen of *Discocyclina*, of about the same size, from Florida shows the small papillæ distinctly.

There is a single spherical embryonic chamber, 0.10 millimeter in diameter. The chamber cavity is filled with calcite which is cracked, but no dividing wall could be discerned. The chamber wall is relatively thick, about 0.012, or about one-eighth the total diameter of the chamber.

The meridional chambers vary considerably in size and proportions. Usually the radial length exceeds the tangential width. Near the center the dimensions are about 0.037 millimeter long by 0.025 millimeter wide; about 0.6 millimeter from the center they are about 0.05 millimeter long by 0.031 millimeter wide; near the periphery some chambers are squarish, 0.038 millimeter long by 0.038 millimeter wide. The shape is oblong or squarish. Although the chambers are approximately concentric, there is irregularity, as the illustration, plate 36, figure 8, shows. The lateral walls of the chambers in successive cycles alternate with each other in position, and thereby produce a slight zigzagging of the boundaries between the chambers in successive cycles, but the zigzagging is so slight that the chambers are usually subrectangular in form. The chambers are different from both the Lepidocycline forms and *Discocyclina*, but possess considerable resemblance to those of *Cycloclypeus gumbelianus*.

No vertical section is available for description.

Locality: El Cristo, Vera Cruz, Mexico. El Cristo well number 1; depth, 3775 to 3785 feet. Specimen received from Mr. W. S. Adkins, of the "Aguila" Petroleum Company.

Geologic horizon: Supposed to be Eocene, Chicontepec?

Type: U. S. National Museum.

Affinities: When I first examined the specimen above described, I thought it was a species of *Discocyclina* because of the rectangular appearance of the meridional chambers, but the meridional chambers are not really rectangular, as shown by the foregoing description and the illustration; a few chambers are hexagonal, but their arrangement and other features are very different from the Lepidocycline forms. The alternation in position of the lateral walls of the chambers in successive

cycles of chambers is similar to the arrangement in *Cycloclypeus*. Although I have not been able to be so entirely certain of the generic identification as I should like to be, I am referring the species *Orbitoclypeus* on the basis of a figure, *A. tellinii*, published by Silvestri, 1924. The principal source of doubt in my application of the name *Orbitoclypeus* lies in my lack of knowledge of the embryonic chambers of that genus.

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EXPLANATION OF PLATES

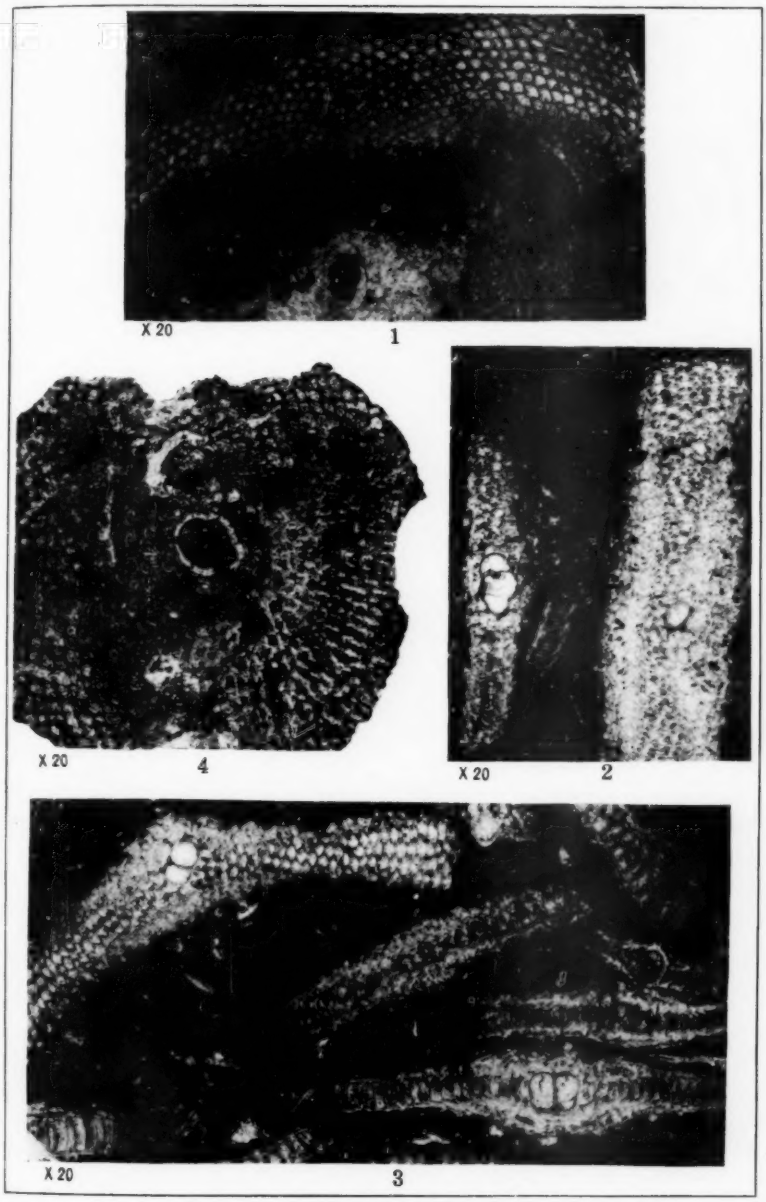
PLATE 30

FIGURES 1, 2, 3.—*Lepidocyclina* (*Polylepidina*) *chiapasensis* Vaughan, new species.

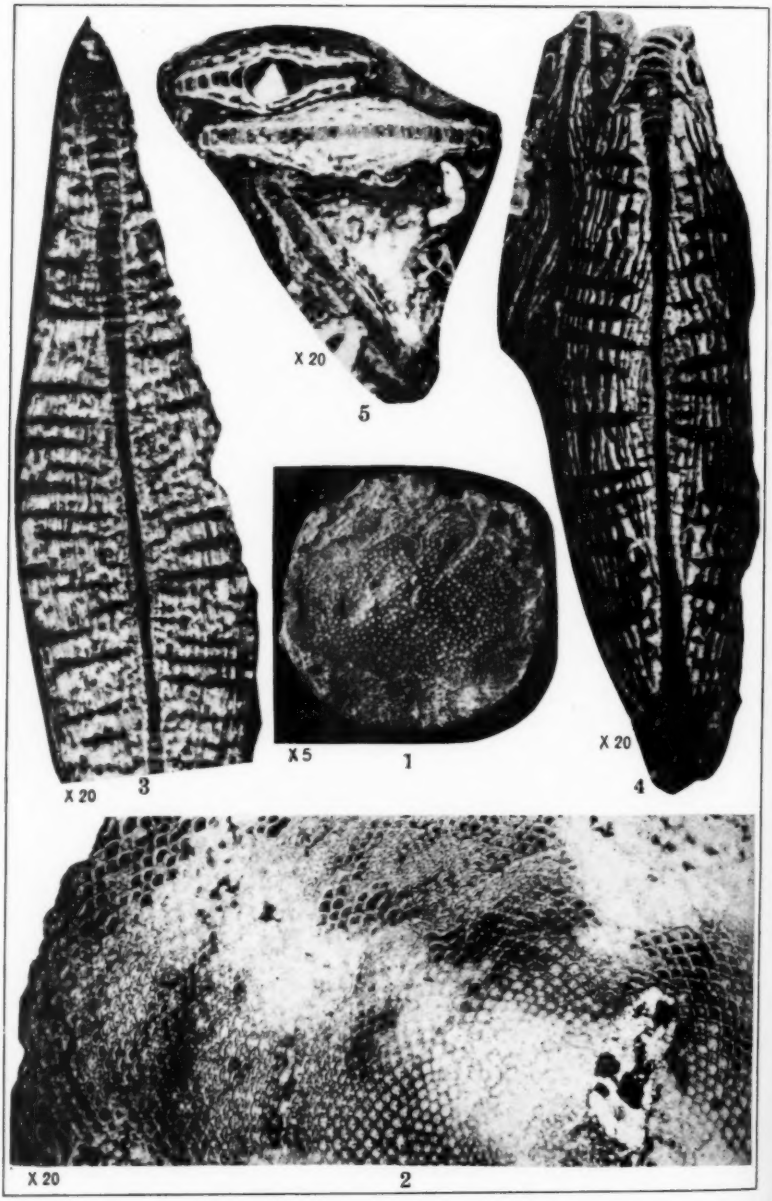
Cotypes, from 3.75 kilometers south and 6.25 kilometers east of Chilon, Chiapas, Mexico. Eocene. Collected by M. F. Nesbit. Figure 1, section in the meridional plane; figures 2 and 3, vertical sections and sections oblique to the meridional plane. All figures × 20.

FIGURE 4.—*Orbitoides media* (d'Archiac).

From 50 miles northeast of Sibi, 8 miles north of Khattan oil locality, Baluchistan, from beds 300 to 700 feet below the Dungham limestone. Upper Cretaceous. Collected by D. Dale Condit. Horizontal section, × 20. Figure introduced for comparison with *Polylepidina.* Note the quadrilocular embryonic apparatus surrounded by a common thick wall.



AMERICAN TERTIARY LARGER FORAMINIFERA



AMERICAN TERTIARY LARGER FORAMINIFERA

PLATE 31

FIGURES 1, 2, 3, 4.—*Lepidocyclina* (*Polylepidina*) *adkinsi* Vaughan, new species.

Cotypes, from 2.75 kilometers south of Triunfo, Chiapas, Mexico. Eocene. Collected by M. F. Nesbit. Figure 1, general view, × 5; figure 2, horizontal section, × 20; figures 3 and 4, vertical sections, × 20. Figure 3 shows a large microspheric specimen and a small, probably macrospheric specimen.

FIGURE 5.—Paratypes, macrospheric specimens, from south side of Tumbalá, on top of Tumbalá Mountain, Chiapas, Mexico. Eocene. Collected by M. F. Nesbit. × 20.

PLATE 32

Lepidocyclina (*Polylepidina*) *proteiformis* Vaughan, new species.

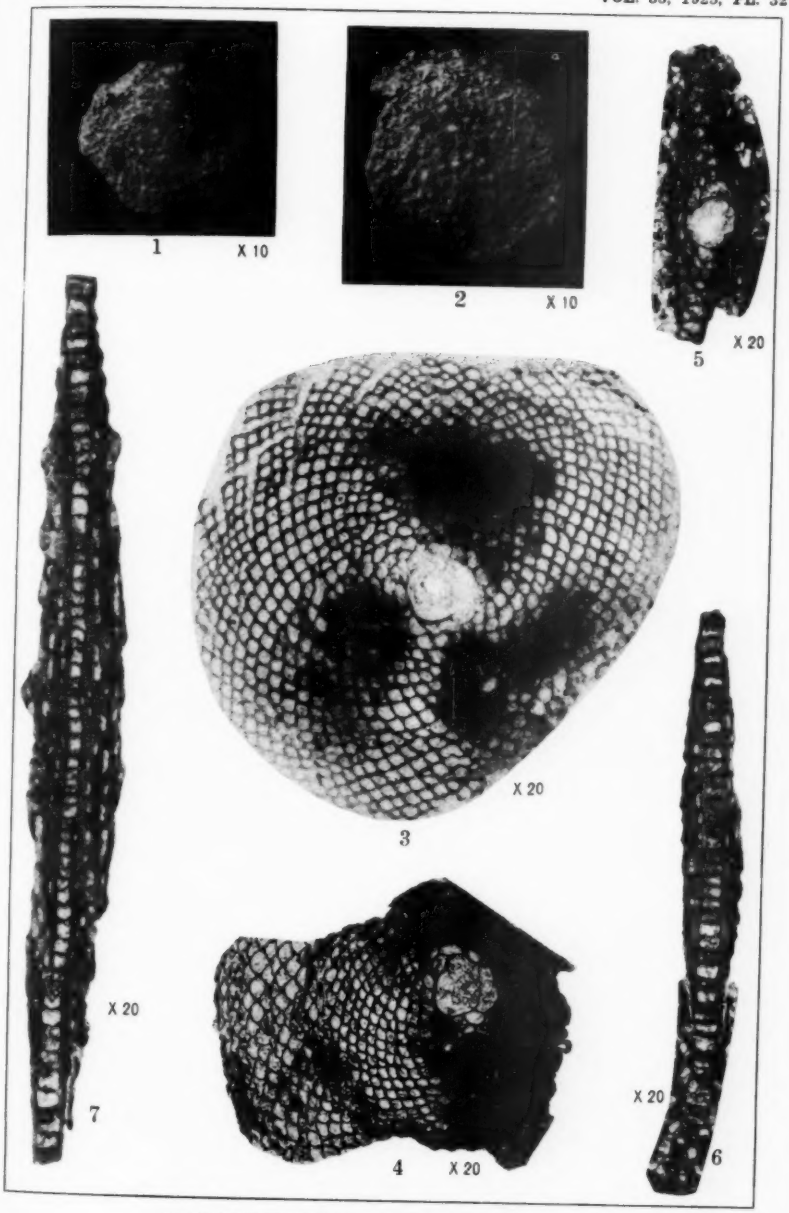
All specimens cotypes from about 0.5 kilometer southwest of Palma Sola, Mecapala Hills, Vera Cruz, Mexico. Eocene. Collected by T. W. Vaughan and D. R. Semmes.

FIGURES 1, 2.—Surface views of two macrospheric specimens, × 10.

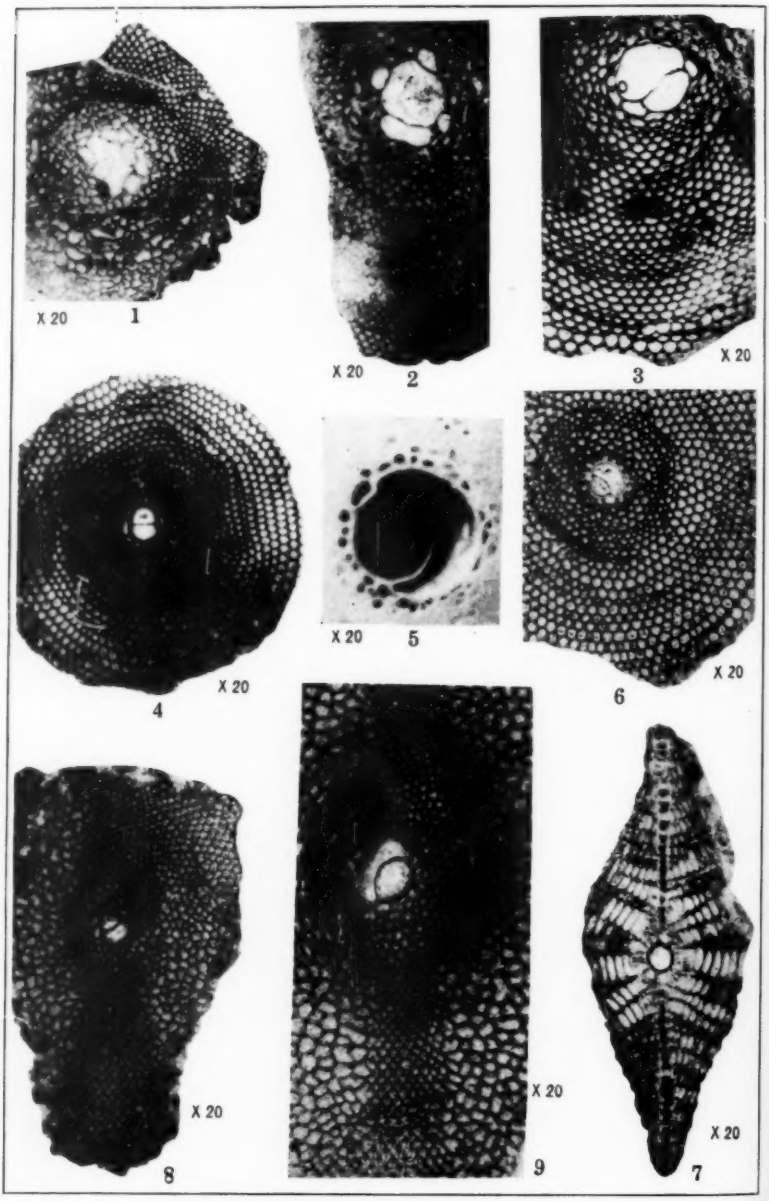
FIGURES 3, 4.—Sections in meridional plane of two macrospheric specimens, × 20. Text figure 6*c* is a camera-lucida tracing of the embryonic chambers of the specimen represented by figure 4.

FIGURE 5.—Slightly oblique vertical section through the embryonic chambers of a macrospheric specimen, × 20.

FIGURES 6, 7.—Vertical sections of two specimens, × 20. Figure 6 is a macrospheric and figure 7 a microspheric specimen.



AMERICAN TERTIARY LARGER FORAMINIFERA



AMERICAN TERTIARY LARGER FORAMINIFERA

PLATE 33

FIGURE 1.—*Lepidocyclina* (*Pliolepidina*) *panamensis* Cushman.

Topotype, from U. S. Geological Survey station 6586*e*, near mouth of Tonosí River, Panama. Probably Upper Eocene, may be Oligocene. Collected by D. F. MacDonald. Pliolepidine embryonic chambers and both lozenge-shaped and rhomboid meridional chambers are shown, × 20.

FIGURE 2.—*Lepidocyclina* (*Pliolepidina*) *duplicata* Cushman.

Specimen from type locality of the species, U. S. Geological Survey station 6523, 2 miles north of David, Panama. Upper Eocene. Collected by D. F. MacDonald. Cushman, 1918*b*, confused the macrospheric form of *L. duplicata* with *L. panamensis*. Embryonic and meridional chambers, × 20.

FIGURE 3.—*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad).

Topotype, from U. S. Geological Survey station 2722, Byram marl, Upper Oligocene, Vicksburg, Mississippi. Collected by T. W. Vaughan. Embryonic and meridional chambers, × 20. The embryonic chambers are isolepidine, compare with text figure 1, which represents *L.* (*Lepidocyclina*) *mantelli* (Morton), but differ from those of *L. canellei* Lem. and R. Douv. The meridional chambers are lozenge-shaped to short-hexagonal, the radial being less than the tangential diameter.

FIGURE 4.—*Lepidocyclina* (*Lepidocyclina*) *canellei* Lem. and R. Douv.

Specimen from U. S. Geological Survey station 6027, Bohio, Panama Railroad, old line, virtually topotype. Culebra formation, Upper Oligocene. Collected by T. W. Vaughan and D. F. MacDonald. Embryonic and meridional chambers, × 20.

FIGURE 5.—*Lepidocyclina* (*Nephrolepidina*) *fragilis* Cushman.

Topotype, from U. S. Geological Survey station 7194, Chipola River, Marianna, Florida, bed number 4 of C. W. Cooke's section. Ocala limestone, Upper Eocene. Collected by C. W. Cooke and W. C. Mansfield. Embryonic chambers, × 20.

FIGURES 6, 7.—*Lepidocyclina* (*Nephrolepidina*) *tournoueri* Lem. and R. Douv.

From Arbol Grande, near Tampico, Tamaulipas, Mexico. Oligocene near the top. Collected by D. R. Semmes. Figure 6, horizontal section, showing embryonic and meridional chambers; figure 7, vertical section, × 20.

FIGURE 8.—*Lepidocyclina* (*Nephrolepidina*) *yurnagunensis* Cushman.

Topotype, from U. S. Geological Survey station 7548, 2 miles south of Yurnaguna, Oriente, Cuba. Oligocene. Collected by O. E. Meinzer. Embryonic and meridional chamber, × 20.

FIGURE 9.—*Lepidocyclina* (*Nephrolepidina*) *vaughani* Cushman.

From Half Moon Bay, Antigua. Oligocene, apparently high. Collected by W. R. Forrest. Embryonic and meridional chambers, × 20.

PLATE 34

FIGURE 1.—*Lepidocyclina* (*Nephrolepidina*) *marginata* (Micht).

From Rio Pantepec, 1.5 kilometers south of Buena Vista Hacienda House, Puebla, Mexico. Collected by T. W. Vaughan and D. R. Semmes. Meson formation, Middle Oligocene. Embryonic and meridional chambers, × 20.

FIGURE 2.—*Lepidocyclina* (*Nephrolepidina*) *chattahoochcensis* Cushman.

Typotype, from U. S. Geological Survey station 3392, Cato Glenn's well, 5 miles southeast of Bainbridge, Georgia. Glendon limestone, Middle Oligocene. Collected by T. W. Vaughan. Oblique section through the embryonic and meridional chambers, × 20.

FIGURES 3, 4.—*Lepidocyclina* (*Nephrolepidina*) *crassata* Cushman.

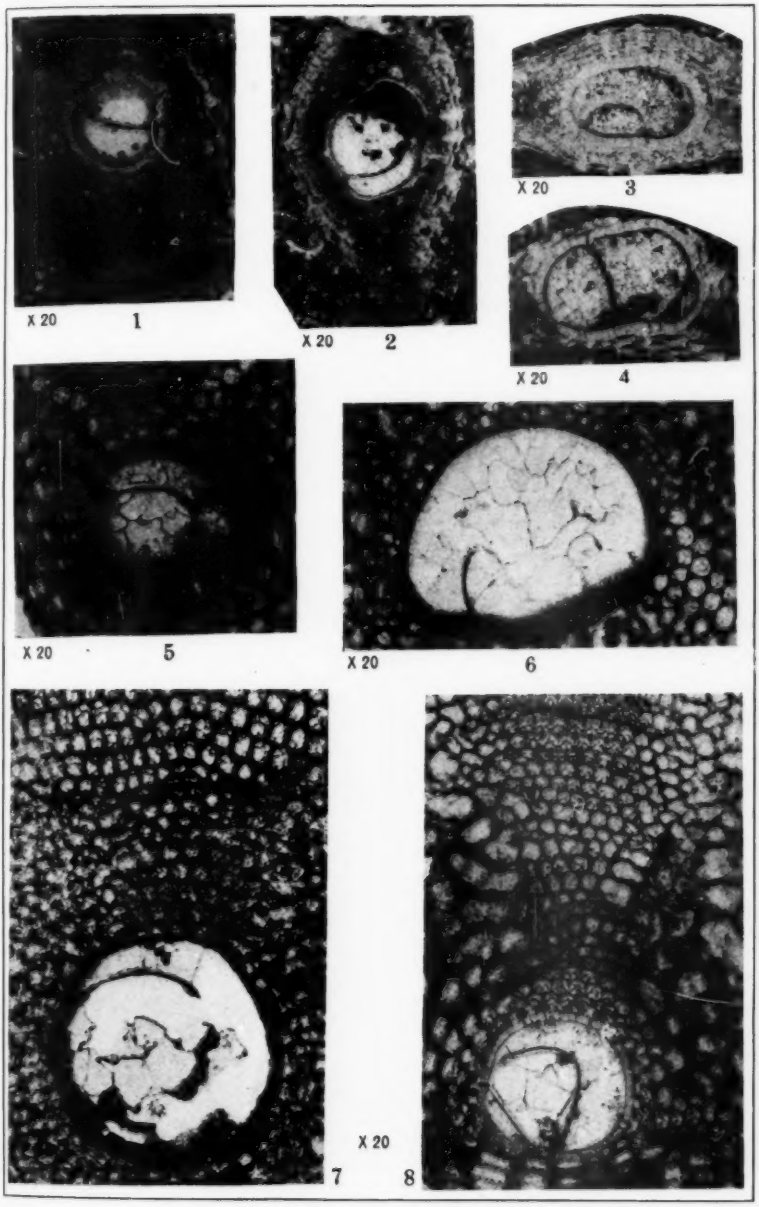
Paratypes, from U. S. Geological Survey station 7519, from orbitoidal limestone, drift, near top of landslide next north of Los Melones, Oriente, Cuba. Oligocene. Collected by O. E. Meinzer. Oblique sections through the meridional chambers, × 20.

FIGURES 5, 6, 7.—*Lepidocyclina* (*Nephrolepidina*) *undosa* Cushman.

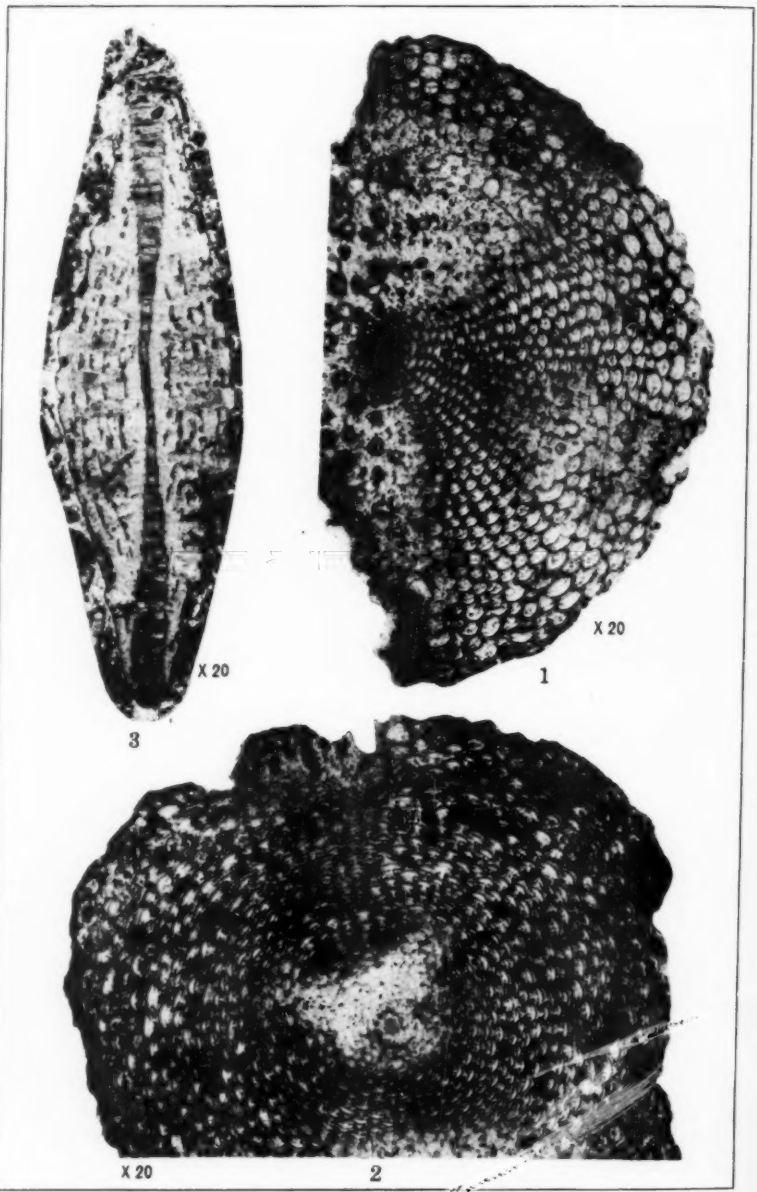
Figures 5, 6, topotypes from U. S. Geological Survey station 6860, Long Island, Antigua, West Indies. Antigua formation, Middle Oligocene. Collected by T. W. Vaughan. Horizontal sections through the meridional chambers, × 20. Figure 7, specimen from 5 kilometers east of Los Naranjos, along the Transcontinental Railroad, Vera Cruz, Mexico; typical Meson formation, Middle Oligocene. Horizontal section through embryonic and meridional chambers, × 20. Note graduation of the nephrolepidine into the eulepidine type of embryonic chambers; also the spatulate meridional chambers. This species is probably a synonym of *Lepidocyclina chaperi* Lem. and R. Douv.

FIGURE 8.—*Lepidocyclina* (*Eulepidina*) *favosa* Cushman.

Topotype, from U. S. Geological Survey station 6881, Willoughby Bay, Antigua, West Indies. Antigua formation, Middle Oligocene. Collected by T. W. Vaughan. Horizontal section through embryonic and meridional chambers, × 20.



AMERICAN TERTIARY LARGER FORAMINIFERA



AMERICAN TERTIARY LARGER FORAMINIFERA

PLATE 35

"Lepidocyclina" antillea Cushman

FIGURES 1, 2.—Topotypes, from U. S. Geological Survey station 6897, conglomerate and sandstone below upper limestone bed, Anse Écaille side of point between Anse Écaille and Anse Lézard, Saint Bartholomew, West Indies. Saint Bartholomew limestone, Upper Eocene. Collected by T. W. Vaughan. Horizontal sections through the meridional chambers, × 20. Note the radial arrangement of the chambers, especially well shown by figure 1, and the closely coiled initial chambers shown by figure 2.

FIGURE 3.—Paratype, from U. S. Geological Survey station 6903, north 67° east from Négre Point, across low saddle back of point, altitude 220 feet, Saint Bartholomew. Saint Bartholomew limestone, Upper Eocene. Collected by T. W. Vaughan. New figure of vertical section of specimen figured by Cushman, × 20.

PLATE 36

FIGURES 1, 2, 3.—*Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman.

Topotypes, from U. S. Geological Survey stations 2638 and 4270, Montgomery, Grant Parish, Louisiana. Jackson formation, Upper Eocene. Collected by T. W. Vaughan at different dates. Figure 1, horizontal section through the embryonic and meridional chambers, × 20. The embryonic chambers are of isolepidine type and the meridional chambers are of intermediate type, lozenge-shaped and rhomboid. Figure 2, part of a horizontal section, × 100, to show perforations in the chamber roofs and floors and details of the chamber walls. Figure 3, vertical section of macroscopheric form, × 20.

FIGURES 4, 5, 6.—*Miogypsina cushmani* Vaughan, new species.

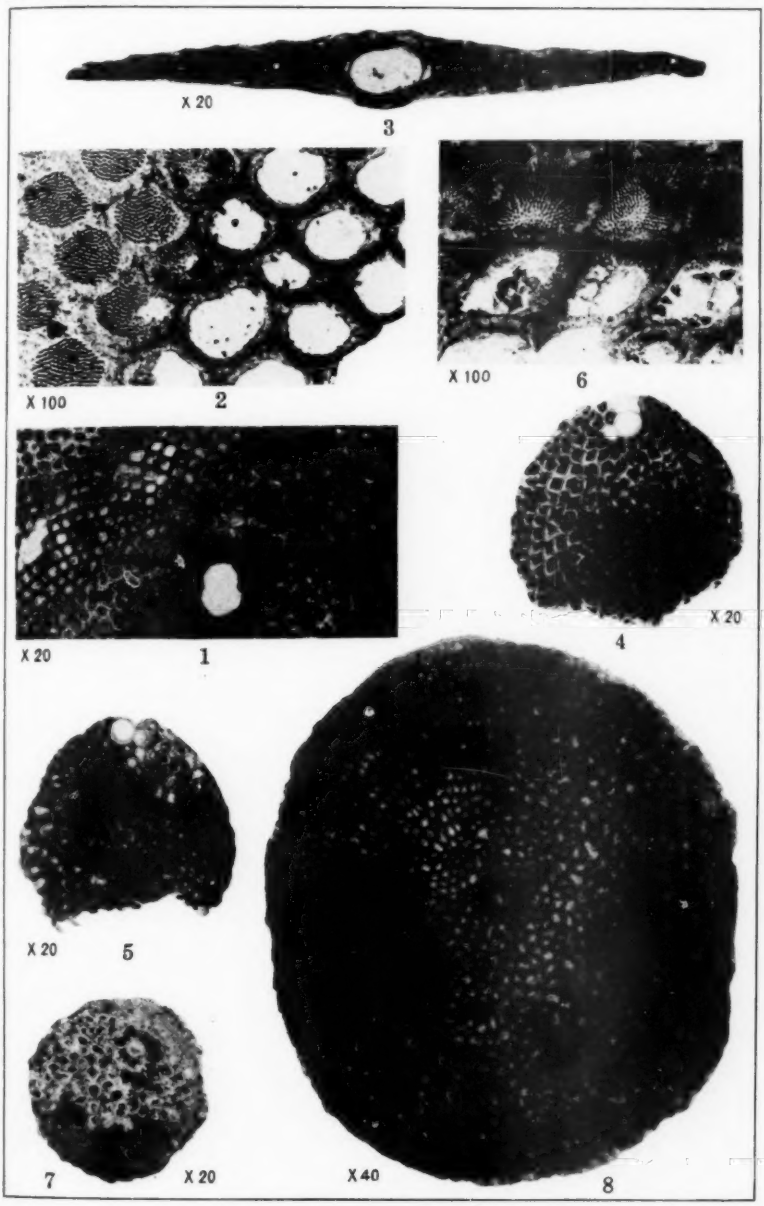
Cotypes, from U. S. Geological Survey station 6012*d*, west side of Gaillard Cut, Culebra, Panama Canal Zone. Culebra formation, upper part uppermost Oligocene or Lower Miocene. Collected by T. W. Vaughan and D. F. MacDonald. Figures 4, 5, horizontal sections to show embryonic and meridional chambers, × 20. Figure 6, part of a horizontal section, × 100, to show perforations in the roofs and floors of the chambers and details of the chamber walls.

FIGURE 7.—*Miogypsina panamensis* (Cushman) Vaughan.

Topotype, from U. S. Geological Survey station 6025, Bohio Ridge Switch, Panama Railroad, relocated line. Collected by T. W. Vaughan and D. F. MacDonald. Culebra formation, Upper Oligocene. Horizontal section to show the bilocular embryonic chambers situated some distance from the periphery, × 20.

FIGURE 8.—*Oribtoclypeus? cristensis* Vaughan, new species.

Holotype, from well, between depths of 3,775 and 3,785 feet, at El Cristo, on Tempoal River, Vera Cruz, Mexico. Probably Lower Eocene. Specimen received from W. S. Adkins. Horizontal section, × 40. The marks across the embryonic chamber seem to be cracks and not partitions.



AMERICAN TERTIARY LARGER FORAMINIFERA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 823-826 DECEMBER 30, 1924
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

AMERICAN AND EUROPEAN TERTIARY CORALS*

BY T. WAYLAND VAUGHAN

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

This paper need be only a note, for I have discussed the relations of the Tertiary corals of America to those of Europe in two of my larger papers. Those of the Eocene and Lower Oligocene corals of the United States are considered in my monograph on that subject,[1] and information on the tropical American Tertiary corals and the later Tertiary of the Coastal Plain of the United States is fully summarized to date in my paper on fossil corals from Central America and some of the West Indies.[2] Both of these publications are available in all large libraries. The only important additional information published since the appearance of the papers mentioned are the lists of corals I contributed to reports on the geology of the Dominican[3] and Haitian[4] republics; an article by me on the stratigraphy of the Virgin Islands of the United States, Vieques Island, and eastern Porto Rico,[5] and the determination by C. T. Trechmann[6] that the "Yellow limestone of Jamaica is of approximately Lutetian age" instead of Upper Eocene age, as I had stated in the second of my papers above cited.

* This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

Manuscript received by the Secretary of the Society September 2, 1924.

[1] References to list of publications at end of paper.

Generic Similarity

Eocene of the United States Coastal Plain and of England and northern France

There is but little identity of species, but there is much generic similarity between the Eocene of the Coastal Plain United States and the Eocene of England and northern France. Both regions have *Flabellum, Sphenotrochus, Trochocyathus, Paracyathus, Turbinolia, Madrepora* (*Diplhelia*), *Eupsammia, Balanophyllia,* and other genera in common. There is similar faunal facies, notwithstanding the presence both in America and Europe of genera which are known from only one of the two continents, but I recognized only one species, *Balanophyllia desmophyllum* M. Edw. and H. as common to both regions.

West Indies

In the West Indies there are two tie points with the European stratigraphic column. These are between the Upper Eocene of Saint Bartholomew and the Priabonian of northern Italy, and between the Middle Oligocene Antigua formation of Antigua, at least the lower part, with its stratigraphic equivalent, the Glendon limestone of Florida, and the Rupelian of Castel Gomberto and other places in northern Italy.

Among the genera common to Saint Bartholomew and the Priabomian are *Stylophora, Astrocoenia, Leptoria, Dendracis, Actinacis, Goniopora,* and other genera. The faunas are similar in facies, and the fauna in each locality has associated with it other groups of organisms which show that the age is Upper Eocene.

The Middle Oligocene coral fauna of tropical and subtropical America contains the following genera in common with the Middle Oligocene (Rupelian) fauna of Italy: *Stylophora, Stylocoenia, Astrocoenia, Euphylia, Orbicella, Antiguastrea, Goniastrea, Hydnophora, Trochoseris, Mesomorpha, Mycetoseris, Cyathomorpha, Astreopora, Actinacis, Goniopora, Porites, Alveopora,* and probably several others. Because of the abundance of *Stylophora, Astrocoenia, Antiguastrea,* and *Cyathomorpha* in both the American and Italian Middle Oligocene, the faunas look very much alike and some of the species are very nearly related if not actually identical. It was because of this similarity between the coral faunas that I correlated the reef-coral horizon of Antigua and its equivalents elsewhere in America with the Rupelian of Italy.

There is considerable similarity between the Miocene coral faunas of America and these of Europe, but this subject does not need extended discussion here.

List of Publications cited

1. T. W. Vaughan: The Eocene and Lower Oligocene coral faunas of the United States, with descriptions of a few doubtfully Cretaceous species. U. S. Geological Survey Monograph 39, 1900, 263 pages, 24 plates. See especially page 32.
2. ———: Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent coral reefs. U. S. National Museum Bulletin 103, 1919, pages 189-524 + xiv, plates 68-152, 25 text figures.
3. ———: List of corals in T. W. Vaughan and others, A geological reconnaissance of the Dominican Republic. Dominican Republic Geological Survey Memoir, volume 1, 1921, 268 pages, 23 plates. Paleontology on pages 89-168.
4. ———: Lists of corals in W. P. Woodring and others, Geology of the Republic of Haiti. Republic of Haiti Geological Survey, 1924, 631 pages, 40 plates, 37 text figures. Lists of fossils, including corals in the section on sedimentary rocks, in part 2, pages 84-259.
5. ———: Stratigraphy of the Virgin Islands of the United States and Culebra and Vieques Islands, and notes on eastern Porto Rico. Washington Academy of Science Journal, volume 13, 1923, pages 303-317.
6. C. T. Trechmann: The yellow limestone of Jamaica and its mollusca. Geological Magazine, volume 60, 1923, pages 337-367, plates 14-18.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 35, PP. 827-846 DECEMBER 30, 1924
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

RELATIONS BETWEEN AMERICAN AND EUROPEAN TERTIARY ECHINOID FAUNAS*

BY G. STEFANINI †

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

Both American and European students of Tertiary Echini have, as a rule, failed to make any comparisons between species on the opposite sides of the Atlantic. Only Guppy and Cotteau[1] reported some species

* This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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as common to both regions, and Gregory,[2] after a visit to the collections in the United States, wrote an interesting article on this subject.

In order to prepare for a more detailed investigation of the subject,[3] I attempted some time ago to summarize the publications on the fossil Echini of North America and I described a few new or little known species. This was a difficult task, because the literature is scattered and much of it is not easily found in Europe. My work soon lost a part of its importance because of the appearance, four years later, of the great monograph by Clark and Twitchell, which was based on a greater wealth of material than that combined in the museums of Paris, London, and Genoa.

The very rapid advance made by American students during the last ten years, combined with the valuable contributions by the European echinologists to the knowledge of the faunas of their country, would have made necessary doing over again the work I had done, but which was never published.

I am, therefore, very grateful to Dr. T. W. Vaughan, President of the Paleontological Society, for having honored me with an invitation to treat this thesis at the symposium of this year, thereby giving to me an opportunity to return, with a greater abundance of data, to a subject of especial interest to me. The material for comparison and the opinions on the correlations of the Tertiary formations of the Coastal Plain, furnished me by him and C. W. Cooke, have been valuable in facilitating my work. I therefore express my best thanks to both of them.

In order to proceed with this work, I was obliged to base my comparisons not only on my direct knowledge, but also on an enormous bibliography of more than 200 echinological memoirs and notes,[4] which have been accurately examined and compared with the monographs by Cotteau,[5] Cottreau,[6] Lambert and Thiéry,[7] etcetera, on the echinoid faunas of Europe.

On the American echinoid faunas I had, however, the recent monographs by Clark and Twitchell[8] and Jackson.[9] I have confined myself to the papers by these authors and two recent notes by Lambert.[10] I have, however, introduced some changes in the names of the genera, without which comparisons would have been impossible, because the affinities between the faunas would otherwise have been concealed by differences in nomenclature.

I regret that circumstances do not permit me to present a more detailed and more extensive discussion of this interesting subject.

Eocene

European Faunas

The echinoid fauna which was found in Europe at the beginning of the Eocene was very different from that of the Cretaceous. The deep-sea Ananchytidæ of the Mediterranean "scaglia" and French "craie" disappeared entirely from the prevailingly neritic formations of the Cenozoic, and evidently survived only on abyssal bottoms, where the existence of their Recent representatives has been discovered by the dredgings of oceanographic expeditions. Many genera, as *Pseudodiadema, Echinoconus, Caratomus,* etcetera, became extinct at the end of the Cretaceous.

Along with some Cretaceous remnants, which disappeared in a short time (*Goniopygus, Micraster*), were especially developed Cassiduloida (*Plesiolampas, Cassidulus*) and Brissida (*Prenaster, Cyclaster, Linthia*), destined to evolve into a great number of forms in the Middle Eocene.

The Lutetian transgression caused the dispersal of a tropical fauna, with evident Indo-Pacific affinities, in which the "irregular" greatly prevail above regulars; they are Conoclypeidæ, Eoscutidæ (*Sismondia, Fibularia*), Cassidulidæ (*Amblypygus, Echinolampas*), Spatangidæ (*Eupatagus, Maretia*), Brissidæ (*Paraster,*[11] *Prenaster, Pericosmus, Brissopsis, Macropneustes,* etcetera)—over 100 different genera in all.

In the Upper Eocene, or Priabonian, finally, first appeared in Europe some very rare cryptogenetic genera and families, which reached the maximum of their development in the Oligocene and Miocene; they are the first species of *Clypeaster* (s. gen. *Biarritzella, Palæanthus, Laganidea*) and of the Scutellidæ (*Præscutella*).

From the beginning of the Eocene two zoogeographic provinces were distinguishable in the European region, and they remained more or less clearly marked during all the Cenozoic. They were: (1) The Mediterranean Province, which extended from Spain and Aquitaine, through the Alps, to the Crimea and Cyrenaica; thence through Egypt and Persia, and closely connected with India and Malaysia to form a great tropical Indo-Mediterranean realm. (2) The Northern Province, of which we know only a transition district, is the Anglo-Belgian basin.

The Indo-Mediterranean Province had a great number of characteristic Echini which seem never to have reached the northern region, from which the reef-building corals and the gigantic *Nummulites* were also excluded. These Echini are: *Porocidaris schmideli, Rhabdocidaris, Fibularia, Conoclypeus, Amblipygus, Plesiolampas, Ilarionia, Pericosmus,* and many others, among which are the primitive species of *Clype-*

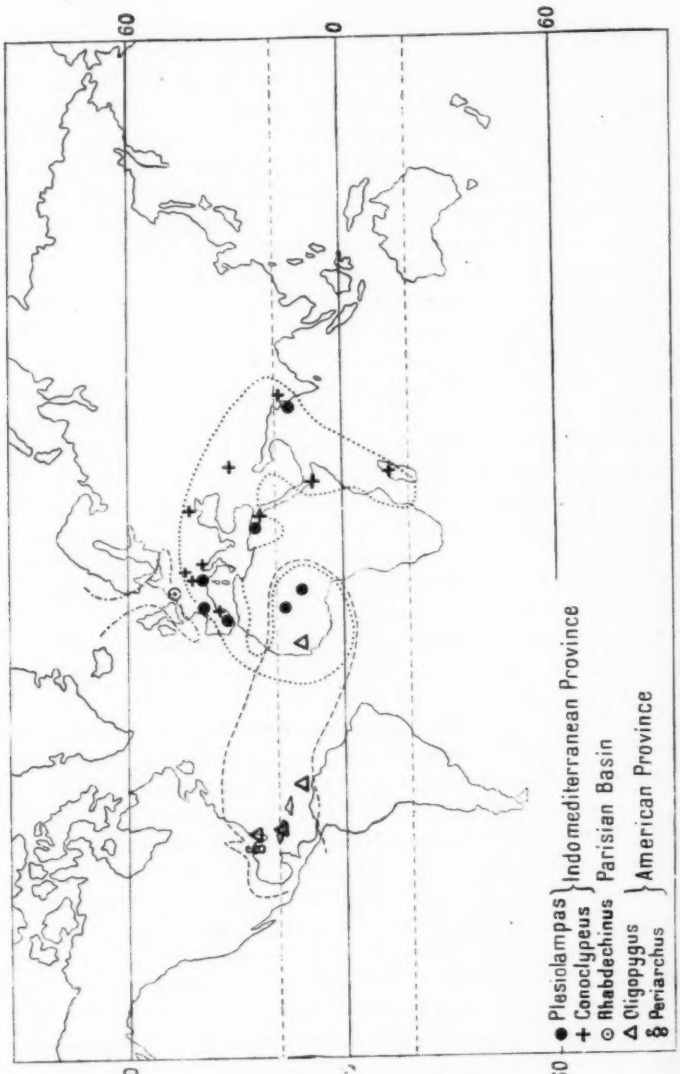

FIGURE 1.—*Distribution of Echinoid Genera in the Eocene*

aster. The Northern Province, on the other hand, was characterized by such genera as *Rhabdechinus* and *Moiropsis*.

At the time of the Lutetian transgression some Indo-Mediterranean Echini penetrated into the northern basin, and with them were the gigantic *Campanile, Velates schmideliana,* and other tropical shells well known to malacologists.

At the end of the Middle Eocene (Auversian) and in the Upper Eocene (Priabonian) the communications between the European basins persisted and the first appearance of some cryptogenic types is noted: the Clypeastridæ[12] coming, in my opinion, from the Indian district, crossing the Mediterranean; and the Scutellidæ, whose origin, according to my idea,[13] is certainly Atlantic and whose introduction into the European basin shows the opening of more ready communication with the occidental seas (figure 2).

AMERICAN FAUNAS

In America, as well as in Europe, the Eocene begins with the extinction of numerous Cretaceous forms (*Pseudo-diadema, Holectypus, Conulus, Discoidea, Cardiaster, Holaster,* etcetera), and the Lower Eocene (Midway) fauna, from what we know, might be considered autochtonous (*Echinanthus, Linthia*). The echinoid fauna of the Middle Eocene (Claibornian), along with common ubiquitous species of no zoogeographic value (*Cidaris, Psammechinus,*[14] *Echinocyamus, Fibularia*), includes the first known Scutellidæ: *Protoscutella mississippiensis*[15] and *Periarchus lyelli.* The development of the Scutellidæ then becomes prevalent in the Upper Eocene (Jacksonian, Ocala), where, with *Periarchus, Mortonella, Peronella,* and *Rumphia,*[16] are found Eoscutidæ (*Fibularia, Sismondia*), Cassidulidæ (*Oligopygus, Amblypygus, Cassidulus, Echinolampas*), Spatangidæ (*Eupatagus, Sarsella*), Brissidæ (*Paraster, Linthia, Brissopsis, Prenaster, Agassizia,* etcetera).

Naturally there are many genera common to the whole American region, as *Sismondia, Echinolampas, Macropneustes,* and, above all, *Oligopygus,*[17] really a most extraordinary type, unknown in all the European or Indo-Pacific basins, but widely distributed in the Coastal Plain, in the West Indies, and on the African coast of Senegal.[18] Nevertheless, continental America and the West Indies formed in the Eocene two absolutely different provinces. It is enough to say that, out of over eighty Upper Eocene species, the authors have not indicated even one species in common, but only some very rare representatives (for instance, *Eupatagus clevei* and *E. floridanus*). The Scutellidæ, with five genital pores, which has been alluded to above, remain characteristic in continental

FIGURE 1.—*Distribution of Echinoid Genera in the Eocene*

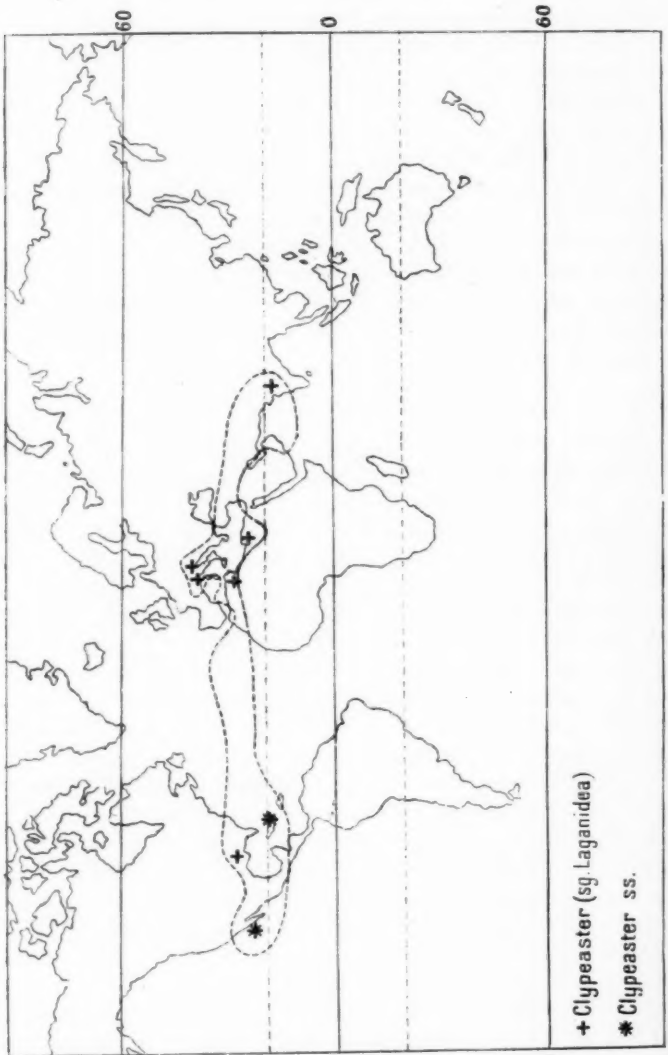

FIGURE 2.—*Distribution of Clypeaster, s. s., and Clypeaster (sg. Laganidea)*

America; the only Scutellidæ known in the West Indies (*Peronella*) belong to a different tribe (*Echinodiscinæ*), and with it we find characteristic in the West Indies *Plagiobrissus, Prosostoma,*[19] *Breynia,* etcetera.

A third Atlantic region, which establishes in some way a kind of acclimatization basin between those of America and Europe, is the province we call the Nigerian, which, however, runs into the heart of Africa, almost as far as Lake Chad.[20] There, in nummulitic deposits of unknown horizon, and perhaps not even closely contemporaneous, but certainly of Eocene age,[21] one finds with *Oligopygus* (whose Atlantic character we have just indicated) *Plesiolampas* (which instead is Indo-Mediterranean), a *Fibularia,* which is considered similar to an Egyptian and Cyrenaic species, and then *Rhabdocidaris, Echinolampas, Hemiaster,* etcetera.

RELATIONS BETWEEN THE TWO FAUNAS

The comparison between Lower and Middle Eocene faunas of America and Europe shows some general uniformity of evolution by the presence of many genera in common (especially among those more widespread or more long-lived) and by the preponderance of the same families, but a close examination proves that marked differences existed between them. Nevertheless, the relations became somewhat intimate in the Priabonian (Jacksonian), when foreign elements undoubtedly immigrated (as *Amblygus* in America and *Præscutella* in Europe) and related species in each region (as *Rhabdocidaris foveata* and *Rh. pouechi, Agassizia inflata* and *Anisaster gibberulus, Echinolampas clevei* and *E. cachaouensis,* etcetera) were united in the faunas to surviving native species (*Fibularia meridionalis,* etcetera) and to the products of the evolution *in situ* of local Middle Eocene types (*Periarchus*).

These facts can be explained if we suppose that the east and west Atlantic regions remained apart from one another during the Lower Eocene and a greater part of the Middle Eocene. It is about the end of this period or at the beginning of the Jacksonian that a way was opened between them, or at least that the communication became somewhat easier between the opposite sides of the Atlantic.[22] In this manner we can also explain why the Scutellidæ, which were present in America since the Claibornian, did not appear in Europe until the Priabonian (Jacksonian), while *Amblypygus dilatatus,* an element characteristic for the Lutetian Mesogæa from India and Madagascar through the Præmediterranean as far as Spain and Aquitaine, was not present in America in the Claibornian, but appeared late in Jacksonian with two representative species—*A. merrilli* in Florida and *A. americanus* in the West Indies—

FIGURE 2.—*Distribution of Clypeaster, s. s., and Clypeaster (sg. Laganidea)*

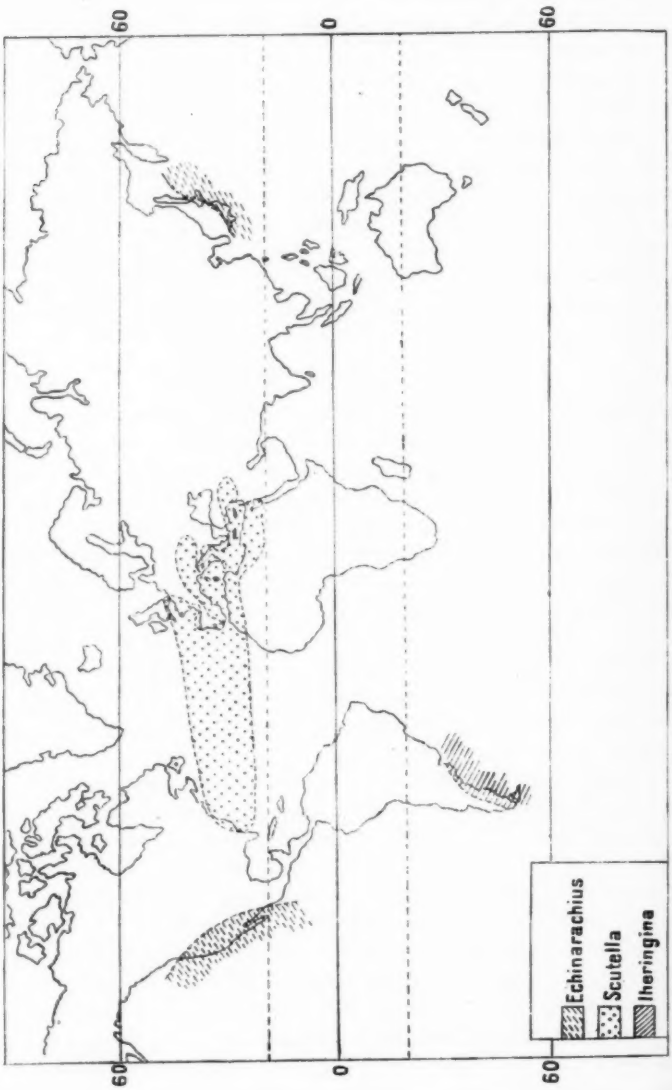

FIGURE 3.—*Origin and Distribution of Echinoid Genera*

perhaps two local varieties of one and the same species. The late introduction of *Clypeaster* into the American Mesogæa could find a satisfactory explanation in this hypothesis (figure 3).

OLIGOCENE

EUROPEAN FAUNAS

In the Eocene we are in the presence of a fauna very much impoverished by the extinction of a great number of genera (about 60), while the genera which first appeared in this period are very few. We can, however, note the presence of many Scutellidæ, among which some were peculiar to the northern basin (as *Scutulum*) and others (*Scutella, Tretodiscus*) were confined to the Mediterranean region. Generally they were produced by the development *in situ* of native types; and the same is true especially for *Clypeaster,* of which many subgenera proceeded from the evolution and differentiation of local Eocene types. The cases of immigration or of cryptogenesis seem to have been very rare in the European Oligocene, and generally consisted in the introduction of isolated genera, generally from the Atlantic or northern seas (figure 4).

The zoogeographical partition delineated in the Eocene persisted in the Oligocene; the Præmediterranean basin continued to be distinguished from the north European basin by the presence of *Clypeaster, Echinoneus, Echinocardium,* etcetera, and by the lack of *Spatangus* and *Moira,* although communication between them was probably easy. It also maintained close relations with the Indo-Pacific basin (*Tretodiscus, Palæanthus, Laubeanthus,* etcetera), with which it even had some species in common; but at the same time the bonds were becoming close also with the western shore of the Atlantic.

AMERICAN FAUNAS

As in the case of the European Oligocene echinoid faunas, the Oligocene echinoid faunas of the American Province as a whole (Vicksburgian, Antiguan) are also examples of fauna not only very much impoverished because of the extensive extinction of older genera (it suffices to remember the disappearance of the primitive Scutellidæ provided with five genital pores, of *Amblypygus, Eurhodia, Oligopygus,* etcetera), but also prevailingly autochthonous. Nevertheless, in the Coastal Plain Province as well as in the West Indies there were present foreign genera, among which are *Echinarachnius,* of California or Japanese origin;[23] *Anomalanthus,*[24] Australian; *Clypeaster* s. s.,[25] typically American, also in the Neogene and Recent seas, but probably branching from an Indo-Pacific

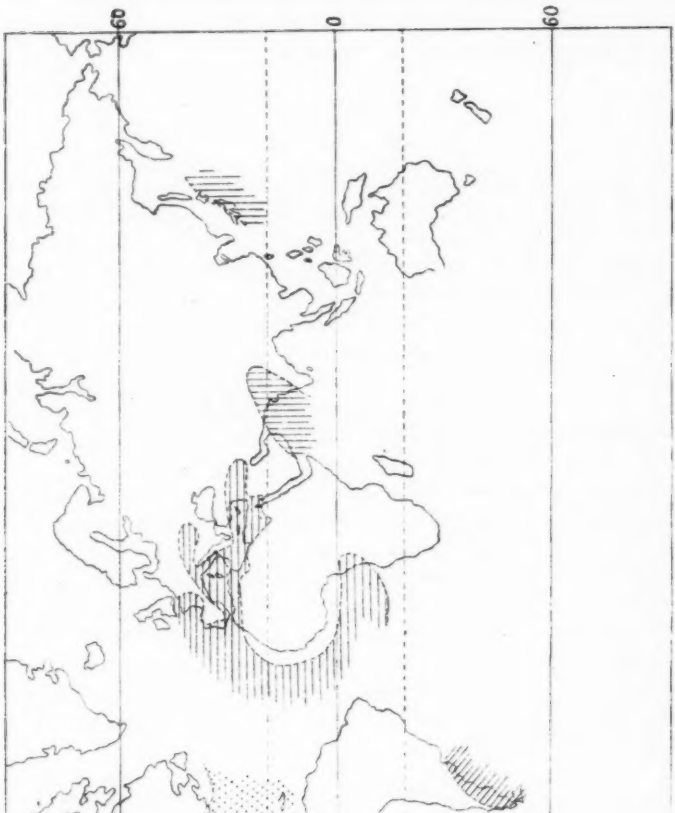

FIGURE 4.—*Distribution of Echinoid Genera*

stem; and *Clypeaster* (subgenus *Laganidea*), coming, on the contrary, from the Præmediterranean.

RELATIONS BETWEEN THE TWO FAUNAS

Although the two American provinces were very clearly distinct and each contained a different fauna in the Oligocene, each had close relations with the European provinces, especially with the Mediterranean Province, which belonged to the Mesogæa, as, for instance, *Echinolompas lycopersica,* from the West Indies, is the representative of *E. chericherensis,* from Cyrenaica and Tunisia, while *Clypeaster rogersi,* from the Coastal Plain, is very closely allied to *Cl. biarritzensis.*

The distribution of the Clypeasters, connected, as is well known, with the Tethys or Mesogæa during the whole Tertiary, must be particularly considered; but, above all, it is significant that the above cited subgenus *Laganidea,* which was present in India and the Præmediterranean and American provinces, was absent in the north European basin. It is characteristic of all the Oligocene Tethys, and clearly shows that the American, even Coastal Plain basin, had already begun to be a part of the Mesogæa, from which it had remained more or less excluded during the first half of the Eocene.

All these facts and the above-mentioned western and eastern affinities of the American echinoid faunas demonstrate that inter-interoceanic as well as transatlantic communication was easy in Oligocene time.

TRANSITIONAL FAUNAS BETWEEN OLIGOCENE AND MIOCENE AND THEIR RELATIONS

A great difference of stratigraphy and tectonic history can be observed between the Mediterranean and West Indies regions with regard to the transition from the Oligocene to the Miocene. In southern Europe and many parts of northern Africa the Chattian stage is very rarely represented by sediments of a marine facies, and the Aquitanian, nearly everywhere transgressive[26] (where it is not continental), marks, therefore, a clear break, both stratigraphic and paleontologic, with the Oligocene series. In the West Indies, on the contrary, the Chattian-Aquitanian series (Anguillan stage) shows a uniformly marine facies, which seems to be indivisible on the stratigraphic point of view and has a good number of species in common with the underlying Antiguan stage. Consequently the modern geologists of Europe put the Aquitanian at the base of the Miocene, while the Americans,[26 bis] according to their point of view, prefer to put it at the top of the Oligocene. (See note by T. W. Vaughan at the end of the paper.)

As Chattian echinoids are practically unknown in Europe, we are obliged to limit ourselves to the comparison of the Echini of Anguilla and the contemporary Echini of Panama (Emperador limestone) to the faunas of the Aquitanian in Europe.

Now, next to some surviving species, which we have alluded to (as *Echinolampas lycopersica*, some *Clypeaster* of "American" type, *Paraster clevei, Sismondia anguillæ*, etcetera), we find at Anguilla *Cidaris melitensis* and perhaps some other species in common with the Præmediterranean Province.[27] Besides, *Echinolampas semiorbis* is closely allied to those great species with a hemispherical shape, which I have[28] indicated as "conoclypeiforms" (*Hypsoclypeus auctorum*) because of their apparent likeness with *Conoclypeus*.

Especially instructive is the comparison made by Cottreau[29] between the fauna of Anguilla and that of the reef limestones of Carry (Marseille), as in both we find many rare genera, as *Parasalenia*,[30] *Echinoneus, Brissus*,[31] in the same formation.

At the end of the Oligocene and at the beginning of the Miocene the echinoid fauna of West Indies and Panama has assumed increasing analogy with that of the Præmediterranean.

Miocene

European faunas

In contradiction to what we have said happened in the Oligocene, the Miocene faunas of Europe were very rich in Echini, and many genera newly appeared (about 30), partly locally produced by evolution from Oligocene or Eocene types (as *Brissus* from *Cestobrissus, Schizobrissus* from *Macropneustes, Brissomorpha* and *Peribrissus* from *Saviniaster*), partly immigrant, abundantly counterbalancing those dying out with the beginning of this period.

The Mediterranean basin, which began to spread out in the Miocene, held in all about 70 genera, for the greater part Echinometridæ (especially *Echininæ*), Scutellidæ, and Clypeastridæ, which impart to these faunas a distinctive aspect; and in addition to these there were several long-lived types of Cassidulidæ, Spatangidæ, and Brissidæ. Worthy of special attention are also some genera with a deep-sea or archaic facies, as *Toxopatagus* (a real Miocene *Hemipneustes*),[32] *Cleistechinus*, allied to the deep-sea *Argopatagus*, and *Heterobrissus*,[33] *Linopneustes, Phormosoma*, etcetera, the abundance of which seems to show that the orogenic post-Miocene Alpine phase must have caused the emergence of geosynclinal deposits.

In the east the Mediterranean region included Egypt, Asia Minor, and Persia as far as Luristan;[34] further south the Indo-Pacific Province began in India and southern Arabia. The Mediterranean Province at the north included the extra-Alpine basins of Rumania, Austria, and Switzerland; toward the west, that of Portugal and Aquitaine. Nevertheless, nearer the north, along the Atlantic coasts, the "Celtic" basin (Bretagne, Touraine, Loire) formed a zoogeographic unit characterized by the lack of *Clypeaster* (as usually tropical), *Echinoneus, Agassizia,* and by the existence of northern types (*Spatangus, Strongylocentrotus*).[35] To the south, one finds at Loanda, on the west coast of Africa, an *Amphiope* (*A. neuparthi*), an exclusively Miocene and typically Mediterranean genus, although it also extended to the transitional basin, which we have called "Celtic." Finally, Madeira and the Canary Islands were also included in the Mediterranean Province, since they have several species and genera in common with it.

AMERICAN FAUNAS

If one neglects, as we have done, the Anguillan stage, which is to be considered in a certain way intermediate between the Oligocene and Miocene, the American echinoid faunas become very scant. In the first place, there are few species in the Gatun formation (Panama), which corresponds with the Burdigalian and contains a *Clypeaster* s. s. allied to *Cl. bowersi* from California, a *Schizaster* very similar to some species of the same genus from the Mediterranean (*S. calceolus*), and several *Encope,* a local genus of Scutellidæ with lunules, which appeared for the first time in the Miocene and which corresponds, in a different phylum, to the same phase of evolution that was reached, also in the Miocene, by the eastern Atlantic *Amphiope.* (See note by T. W. Vaughan at the end of the paper.)

The "Oceanic Series" of Barbados has offered a *Cystechinus,* which by its abyssal facies reminds us of the above-mentioned deep-sea types of the Mediterranean, showing[36] that also in the West Indies the "Alpine" period of folding uplifted geosynclinal deposits.

RELATIONS BETWEEN THE TWO FAUNAS

In the analysis of the two faunas, I have already alluded to the common and representative species.

Of the two basins which existed in America in this period, that of the Coastal Plain, by the absence of *Clypeaster* and by the presence of *Echinocardium* and perforated Scutellidæ, presented features similar to those of the Celtic basin of Europe. I think that it must have received immi-

grants from the northern seas. The Panamic-West Indian province was, however, more in connection with the Mediterranean, and it also belonged to the Mesogæa. The closest affinities between the two are observed, however, at the beginning of the period. Later on, although the relations remained very close, the two faunas became more different, in the sense that each one shows a tendency to assume affinity with the present faunas of the same regions, by the development in each one of characteristic genera (as *Clypeaster* s. s., *Encope, Mellita,* etcetera, in America and *Coronanthus, Spatangus* in the Mediterranean).

Pliocene

European faunas

The end of the Miocene is marked in all the European seas by the dying out of a great number of genera and species, and the few Echinoidea which immigrated or first appeared in this period fall far short of compensating for so many losses. There were about 30 genera among the most characteristic (deep-sea and especially tropical forms) which completely disappeared or persisted only in the warm seas, while the genera which first appeared in Europe with the Plaisancian (Lower Pliocene) transgression were few in number and all belong to cold or temperate seas—*Echinus, Sphærechinus, Temnechinus.* The few genera of a tropical type remaining (*Clypeaster,* subg. *Pliophyma, Echinolampas*) were represented by few species, plainly in regression and for the most part destined to disappear before the end of the Pliocene, while several surviving forms, on the contrary, belong to those genera which had reached Neogene Mediterranean from the northern basin, also of a "cold" type (*Spatangus, Strongylocentrotus*). The "tropical affinities" claimed for the echinoid faunas of the English crags are very doubtful;[38] it matters not in what respect the Anglo-Belgian basin showed a more "northern" than a more Mediterranean aspect.

The Mediterranean basin was reduced in the Upper Miocene to a series of brackish or over-salty swamps (Pontic), in which the Echinoidea, *par excellence* stenohaline animals, could not live, except in the narrow "Sahelian" Channel, and because of these changed conditions several types were killed. Consequently, when the sea again invaded this region with the Plaisancian transgression, it was the northern Atlantic waters which penetrated it, carrying its fauna with it.

In the Pliocene we are in the presence of a condition of things analogous to that we have seen in the Middle and Upper Eocene and Oligocene, when Mediterranean and north European faunas were also closely

allied; but the conditions are inverted. In the Paleogene the genera in common to the two basins were of a tropical type and marked a partial ingression of a tropical fauna into the Anglo-Parisian basin. In the Pliocene, however, some north Atlantic genera penetrated into the Mediterranean, and the Miocene remnants (more abundant in the Mediterranean than in the northern basin) formed the main difference between them.

Toward the south, in western Morocco and Rio de Oro, there are indications of a different Pliocene fauna, in the existence of such genera as *Rotuloidea* and *Hemiheliopsis,* the direct ancestors of the recent *Rotula* and *Radiorotula* of the same West African province.

AMERICAN FAUNAS

In America the Coastal Plain basin appears still to belong to the tropical region because of the existence of Clypeasters, among which is *Cl. rosaceus,* also Recent; and other forms, either Recent or allied to Recent ones, are *Encope macrophora* and *Agassizia porifera,* which have their roots in the local Miocene faunas. *Strongylocentrotus dröbachiensis,* however, is introduced into the Maryland basin from the north Atlantic.

The presence of *Clypeaster* assimilates the small fauna of Florida to that of the West Indies, which has also furnished species of *Echinoneus, Brissus, Brissopsis,* and *Hemiaster* identical with or similar to living species. A *Clypeaster* of the subgenus *Coronanthus,* now living in tropical seas and also in the West Indies and Yucatan peninsula is *Cl. meridanensis.*

Both of the American basins had in the Pliocene a tropical character, and therefore their faunas were in that respect different from those of the European basins.

The American as well as the European faunas were derived in part from the reduction of previous faunas; but in America they survived in great number and their association maintained their tropical character, whereas in Europe the local elements were reduced to rare remnants, selected by severe climatic selection, owing to this region being excluded from the tropical zone and depending on the temperate ones.

The displacing toward the south of the climatic limits, which in America was marked by the introduction of *Strongylocentrotus,* had more important effects in Europe, where it was marked by the introduction of a different group of genera rich in species and individuals, which impressed a special aspect on that reduced fauna.

Post-Pliocene and Recent echinoid Faunas

We have now considered, step by step, the history of the echinoid faunas from the beginning of the Tertiary almost to the present time. In Europe, where the Pliocene and Pleistocene echinoid faunas are better known,[39] one can say that these contained in germ nearly all the faunistic elements now living in the neritic zone of the seas of the region, and in addition some forms which died out during the Glacial period (*Stirechinus, Clypeaster, Echinolampas*) and some others which persisted into the post-Pliocene: the deep-sea *Neolampas*[40] and *Arbacia*, a tropical element perhaps introduced in the Postglacial (Tyrrhenian) period with *Strombus bubonius* and other "Guinean" shells.

In America, where the more recent faunas are less known, all the Pliocene and, above all, the post-Pliocene species have, however, their remote or immediate successors in the Recent faunas of the same regions; thus, *Clypeaster ambigenus* from Guadaloupe, *Toxopneustes variegatus, Strongylocentrotus dröbachiensis, Mellita pentapora,* and *Moira athropos* from the Coastal Plain.

Therefore, beginning with the Middle Miocene, but especially in the Pliocene and Pleistocene, one notes that great changes in the composition of the faunas gradually took place, and that the changes lead from one rather homogeneous fauna, inhabiting the middle Atlantic from the Mediterranean to the West Indies, to the two different faunas of the present time—two faunas which are strikingly distinct, but are not without some common elements, whether the fauna be of deep-sea type, of northern origin, or a persistent remnant.

References and Notes

1. R. J. L. Guppy: On Tertiary Echinoidea from the West Indies. Quarterly Journal of the Geological Society, volume XXII, 1866.
[G. H.] Cotteau: Descriptions des échinides tertiaires des iles Saint Barthélemy et Anguilla. K. Svensk. Vetenskaps Akademiens Handlingar, volume 13, number 6, 1875, pages 1-48, plates 1-8.
2. J. W. Gregory: Relations of the American and European echinoid faunas. Bulletin of the Geological Society of America, volume 3, 1892.
J. W. Gregory: A revision of the British fossils Cainozoic Echinoidea. Proceedings of the Geological Association, volume XII, 1891.
3. G. Stefanini: Sugli echini terziari dell' America del Nord. Bollettino Società Geologica italiana, volume XXX, 1911. Note echinologiche. Rivista italiana di Paleontologia, volume XVII, 1911. Contributo degli studi echinologici ad alcuni problemi di Paleogeografia. Rivista Geografica italiana, volume XIX, 1912.
4. It is inappropriate to present here this long list of publications, which can be found partly in other works of mine and, as far as it is necessary, in the following footnotes.

5. G. [H.] COTTEAU: Paléontologie française, Terrains tertiaires. Échinides éocènes. Paris, 1885-94.

6. J. COTTREAU: Les échinides néogènes du Bassin Méditerranéen. Annals Institut Océanografique, volume VI, 3. Paris, 1913.

7. LAMBERT et THIÉRY: Essai de nomenclature raisonnée des Échinides, volumes I-V. Chaumont, 1909-21.

8. W. B. CLARK and M. W. TWITCHELL: The Mesozoic and Cenozoic Echinodermata of the United States. United States Geological Survey, Monograph LIV. Washington, 1915.

9. R. T. JACKSON: Fossil Echini of the Panama Canal Zone and Costa Rica. United States National Museum Bulletin 103, Washington, 1919. Fossil Echini of the West Indies. Carnegie Institution of Washington, 1922. T. W. VAUGHAN: Stratigraphic significance of the species of West Indian fossil Echini. Carnegie Institution of Washington, 1922.

10. J. LAMBERT: Échinides néogènes des Antilles Anglaises. Mémoire Société Académie Aube, volume LXXIX, 1915. Nouvelles observations sur quelques Échinides néogènes de l'île d'Anguilla. Annals Magazine of Natural History (9), volume IX, 1922.

11. Following the practice of American authors, I apply the name *Paraster* to those species of *Schizaster* which are provided with four genital pores. Nearly all the Eocene "*Schizaster*" are *Paraster*. In the Neogene the species *Schizaster* became abundant, together with some *Paraster*, which however, became more and more rare. Compare Tornquis, Die Beschaffenheit des Apikalfeldes von *Schizaster* und seine geologische Bedeutung. Zeitschrift der deutschen geologischen Gesellschaft, volume LV, 1903.

12. Compare J. LAMBERT: Note sur quelques espèces anciennes du genre *Clypeaster*. Annale Société Linnéenne de Lyon, volume LXI, 1914.

13. Compare G. STEFANINI: Osservazioni sulla distribuzione geografica, sulle origini e sulla filogenesi degli Scutellidi. Bolletino Società geologica italiana, volume XXX, 1911.

14. *Echinus exercens* De Greg.

15. *Scutella mississippiensis* Twitch., provided with five genital pores and bifurcated actinal furrows, is very different from the true Miocene Scutellas, which have by definition four genital pores and branching actinal furrows. On the other hand, it differs from *Periarchus* (to which it is, however, more allied), by its more important characters, not so much by the shape, more low and flat, as especially by its periproct on the edge of the test. I apply to this species the name *Protoscutella*. As to *S. tuomeyi* Twitch., it is in some ways intermediate between *Protoscutella* and *Periarchus;* but, nothwithstanding its flattened shape, I would include them in the second of these genera, to which it corresponds by the position of the anus. In any case it is not a *Scutella*.

16. *Laganum eldridgei*, properly compared by Twitchell with *L. elongatum*, must be ascribed to this Indo-Pacific genus, which differs from *Laganum* by its four genital pores, by the periproct being inframarginal, rounded, by its thin edges, etcetera. Compare Lambert et Thiéry, loc. cit., page 312.

17. Compare G. STEFANINI: Note echinologiche III, loc cit. *Oligopygus ovum-serpentis.* The difference in the shape of the peristome of this species is not sufficient to annul the close affinity between *O. ovum-serpentis* or *O. meunieri* and the Coastal Plain species. These seem at the most of a less primitive type, their phyllodes being almost completely atrophied, instead of still being present but reduced. The change of the name to *Oligopygus ovumserpentis*, suggested by me in 1911, was immediately received by the most authoritative echinologists, as Lambert, Cottreau, and Twitchell. Furthermore, if one should consider these species as belonging to a genus different from *Oligopygus*, they would still remain very far from *Echinolampas* and very near to *Oligopygus*, and our conclusion would not be changed.

18. *Oligopygus meunieri* Lambert.

19. Pomel proposed the name *Prosostoma* for *Asterostoma jimenoi* from Cuba. 1883. Compare G. Stefanini, Echini Miocene medio Emilia, Palæontologia italiana, volume XV, 1908, page 34.

20. Although it is not clear whether this west African basin communicated directly with the Egyptian basin through the Sudan, or whether it was connected with the Algerian and west Mediterranean basins, the conclusion about its importance as an "acclimatization basin" between the two regions remains unchanged.

21. The faunas of this basin have never been monographically studied; therefore I give the bibliography on the echinoid faunas from it:

BATHER: Eocene echinoids from Sokoto. Geological Magazine, new series, Decade V, volume I, 1904.

J. LAMBERT in J. CHAUTARD: Note sur les formations éocènes du Sénégal. Bulletin Société Géologie Française (4), volume VII, 1905.

J. LAMBERT: Sur un *Plesiolampas* de l'Afrique Centrale. Bulletin Société Géologie Française (4), volume VI, 1906.

J. LAMBERT: Sur un échinide du Sénégal, *Oligopygus meunieri.* Bulletin Société Naturelle, Ain, volume 21, November 21, 1907, 2 pages, 1 plate.

J. COTTREAU: Échinides du Soudan. Bulletin Société Géologie Française (4), volume VIII, 1908.

HAWKINS: A new species of *Fibularia* from Nigeria. Geological Magazine (1), volume IX, 1912.

22. In America as in Europe (compare Haug, Traité de Géologie, page 1570), the Middle Eocene transgression could have occurred at several different times, the last of which was in the Priabonian. Thus, while in the Coastal Plain we have a completely developed Eocene series (as in the Paris and London basins), in the West Indies it was the Middle or, perhaps, Upper Eocene which was transgressive. (Compare T. W. Vaughan and others: A geological reconnaissance of the Dominican Republic; Washington, 1921; Woodring: An outline of the results of a geological reconnaissance of the Republic of Haiti; Journal of the Washington Academy of Sciences, volume XIII, 7, 1923, etcetera.) This last ingression of the sea might have established communication between America and Europe or, at least, made it possible.

23. I have already shown that these so-called Scutella of California, with their open petals, narrow poriferous zones, their periproct marginal or supramarginal, and the extrapetalous plates differently developed, etcetera, resemble *Echinarachnius* rather than real Scutellas, which are of Neogene age. I know in the British Museum an unpublished species of the same type from the Miocene of Japan. Compare Stefanini, Echini terziarie America del Nord, page 703.
24. *Anomalanthus gregoryi* Lamb., 1915. The only other species of this genus so far known is *A. tumidus* (Woods, *Echinanthus*), from the Australian Tertiary.
25. I explain this group as Lambert (Note sur la synonimie des espèces vivantes de Clypeasters, Annales des Sociétés Linnéennes Lyon, volume LXI, 1914), considering it as $\doteq$ *Diplothecanthus* Duncan.
26. Compare T. W. Vaughan: Correlations of the Tertiary formations of Central America and West Indies. Correlations of post-Cretaceous formations in the Pacific region. Bernice Bishop Museum Special Publication number 7, 1921, page 837.
27. Where one observes an uninterrupted sedimentary series, as, for instance, in many parts of Venice, certain of the few species of Echini there known (*Scutella subrotundæformis*) pass from the Chattian into the Aquitanian beds, and the distinction becomes difficult, as in the West Indies.
28. F. i. *Schizaster scillai* and *S. parkinsoni*, reported by Guppy and Cotteau and Egozcue y Cia. Lambert (Nouvelle observation sur quelques échinides néogènes d'Anguilla, page 392) attributes these determinations to an unexplained "désir de retrouver des formes méditerranéennes dans la région Caraïbe," and, considering "dangerous" the way chosen by the above-mentioned authors, prefers to name the first species *S. egozcuei*, and claims that the second is not *S. parkinsoni*. It remains to be seen if he also does not yield to a preconception of an opposite kind, namely, that there ought not to be any species common to both sides of the Atlantic.
29. G. Stefanini: Conoclipeidi e Cassidulidi conoclipeiformi. Bolletino Società geologica italiana, volume XXVI, 1907.
30. J. Cottreau: Les échinides néogènes du Bassin Méditerranéen, pages 9, 12. Cottreau correctly observes that "l'ensemble de genres ou espèces qui se trouvent dans ces couches est très remarquable, car on ne peut les comparer qu'à certains échinides décrits par Cotteau . . . dans les Antilles."
31. *Echinometra prisca* is a *Parasalenia*.
32. *Brissus* is represented at Carry by a primitive species, of small size, which is not without relations to *Br. exiguus*.
33. Looking through the plates of the monograph by Jackson, one can not help being struck by the close resemblance between *Cardiaster cubensis* and *Toxopatagus italicus;* the only detectable difference is of specific value and consists in the apex being less eccentric. The Cuban species comes from a formation of unknown stratigraphic position, the fauna of which must be very poor, for the assignment of the species to the Cretaceous

is not given as certain by Vaughan. This raises doubt regarding the geologic age of this species. May not the inference as to its Cretaceous age be based on its archaic facies and to its belonging to the Ananchytidæ, and may not the formation at Rio Jateras, Cuba, be of Miocene instead of Cretaceous age?

34. *Heterobrissus montesii* is closely allied to *Asterostoma cubense*, for which Lambert suggests the name of *Antillaster*, but which I think is a real *Heterobrissus*. To this genus belongs also the living *Palæopneustes hystrix*. But *Heterobrissus cubensis* is of Eocene age; therefore one can not conclude that this genus from the West Indian Eocene persisted during the European Miocene and up to the present. Compare G. Stefanini, Echini Miocene medio Emilia, part I, page 95.

35. There is in the British Museum an undescribed species of *Scutella* from Luristan which shows the extension of the Mediterranean province eastward to that place. No true *Scutella* has been reported from India, Malaysia, or Japan.

36. *Strongylocentrotus delaunici* (Cott. *Toxopneustes*). Compare Lambert et Thiéry, loc cit.

37. Compare W. P. Woodring: An outline of the results of a geological reconnaissance of the Republic of Haiti. Journal of the Washington Academy of Sciences, volume XIII, 1923.

38. *Plagionotus pectoralis* is a *Plagiobrissus*. As was also noted by Jackson, *Plagionotus*, being preoccupied, must be replaced by *Plagiobrissus*. This genus fortunately keeps distinct from *Metalia* those Atlantic species which have principal tubercles included in the fascicles. There is in the Mediterranean Miocene, among other species, *P. hungaricus* Vadasz. (Die Mediterraneen Echini Ungarns. Geologie Ungar. I, 2, 1915, tav. X, II.)

39. Compare Gregory: A revision of the British fossils Cainozoic Echinoidea. Loc. cit.

40. Compare G. Stefanini: Probabile origine neocenica degli ambulacri apetali di *Neolampas*. Atti acc. scient. veneto-trentina-istriana, series 3, volume 6, pages 33-41, Padova, 1913.

(Note.—Since the manuscript of Professor Stefanini's paper was prepared the United States Geological Survey has decided for its publications to classify as Miocene the American geological formations regarded as equivalent to the European Aquitanian. This attempt to place the base of the Miocene in America at the same horizon as it is placed in Europe will probably be generally approved by students of Tertiary geology, but the boundary between Oligocene and Miocene in the West Indies and Central America is indefinite. The Gatun formation mentioned by Professor Stefanini as of Burdigalian age is now considered by American paleontologists as being more probably of Helvetian age.—T. W. Vaughan.)

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AMERICAN AND EUROPEAN TERTIARY BRYOZOA[1]

BY F. CANU AND R. S. BASSLER

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

The comparison of the bryozoan faunas of Europe and North America is very difficult for several reasons: First, the rock series are incomplete and never in strict conformity. Second, the European publications are much scattered and do not always correspond to the richness of the formations considered. France especially, with strata enormously rich in bryozoa, has insufficient literature. Third, the hesitations of classification, which commence only when one tries to adjust them, increase the causes of uncertainty. Finally, most of the Tertiary faunas of America and Europe originated in totally different areas. We are able, therefore, to give at this time only an approximate view of the subject.

EARLY TERTIARY BRYOZOAN FAUNAS

In Europe the bryozoan fauna of the Lower Eocene is unknown, for there were then lagoon conditions incompatible to the development of these organisms. Only the Montian has been studied heretofore by Pergens and has furnished a strange mixture of Cretaceous and Eocene forms, the determination of which must be revised.

[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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Near the base of the Aquia formation, in Maryland, the glauconitic sand of the Upper Marlboro section, a most unusual deposit, contains bryozoa and other fossils indicative of the high seas, with nothing comparable to the series of superposed deposits. The fauna so far collected is essentially Cretaceous. The Cretaceous and Eocene deposits of Maryland and New Jersey, being more northern, are in consequence most comparable with the known European deposits. But the association, *Euritina, Cribrilina, Coscinopleura, Lunularia, Heteropora,* and *Ceriopora,* is essentially Cretaceous in Europe since the Cenomanian. Nothing reveals a deposit of Eocene age. The malacological fauna of the Aquia following the glauconitic sand is rigorously that of the famous locality of Bracheux, in France; it is certainly Thanetian, as Heilprin has always regarded it.

The bryozoan faunas of the Midwayan have been collected in Arkansas, Alabama, and Georgia. The affinities are still Cretaceous, with the generic association of *Smittipora, Euritina, Bathosella,* and *Ascosœcia,* but the presence of Recent genera, *Galeopsis* and *Gephyrotes* (appearing in the Cretaceous Vincentown marl), *Gastropella* (occurring at the top of the Cuisian), *Hippoporina* and *Anarthropora* indicates the beginning of the Eocene series as in Europe. But as we have not observed all the genera collected in the London clays and in the superior sands of Cuise-Lamotte in France, we can synchronize the American Midwayan only with the French Sparnacian and the base of the Cuisian.

In regrettable contrast, when really important bryozoan faunas appear in Europe we find nothing in America which can be rigorously compared to them. Between the Midwayan and the Claibornian we have only a small, insignificant fauna found in the Wilcoxian. Here the Cretaceous forms have almost disappeared. The appearance of the genera *Cystisella, Rhamphostomella, Aimulosia, Lunularia,* and *Adeonellopsis* indicate that this stage is in correlation with the superior Cuisian of France and perhaps with the base of the Lutetian of western Europe.

The Claibornian has Lutetian affinities with *Exechonella* (from the Lutetian of southern France), *Adeonellopsis* (from Lutetian of Paris basin), and with the association of *Trochopora, Otionella, Porella,* and *Schizorthosecos.* However, the rich development of the Adeonidæ in the Paris basin has no equivalent in America. The presence of *Vibracellina* and of *Holoporella* and the consideration that almost all the species pass into the Jacksonian permits us to consider the Claibornian as the equivalent of the superior Lutetian and the Auversian.

The fauna from the Jacksonian is one of the most beautiful in the world. Almost all the Recent genera are represented. It is very close,

although much richer than that from the European Priabonian. There are some common species, namely, *Rhamphostomella brendolensis, Gemellaria prima, Callopora tenuirostris, Conopeum hookeri, Acanthodesia savarti, Centronea micropora, Lichenopora verrucosa,* etcetera. There are some genera which appear simultaneously—*Scrupocellaria, Houzeauina, Cellaria, Mastigophora, Retepora,* etcetera.

Oligocene Bryozoa

The Vicksburgian, much less rich, has, nevertheless, afforded an important fauna, very comparable to the German Oligocene deposits, which form in reality only a single stage. There are some common species, as *Lichenopora goldfussi, Stephanosella entomostoma, Smittina strombecki, Smittina angulata,* etcetera. The presence of species of *Metrarabdotos* (from the Latdorfian) leaves no doubt as to the synchronism.

The general evolution on the two continents is not identical. Thus *Nellia* and *Heterocella,* abundant fossils in the Lutetian, are known only in the Vicksburgian. Likewise *Retepora, Cellaria, Tubucellaria, Peristomella,* and *Bracebridgia,* appearing in the Lutetian epoch, have yet been observed only in the Jacksonian. Finally *Trypostega,* appearing in the American Midwayan, is known only in the European Miocene.

Bryozoa of the American Miocene

The comparison of Miocene deposits of bryozoa in America and Europe is not actually possible. The first reason is geographic. In Europe the more important Miocene deposits are found to the north of the fortieth parallel, while in America they are situated to the south. The second reason is bibliographic.

In America the Miocene and Pliocene strata with bryozoa are rare and rather poor, although well studied. In Europe, on the contrary, and especially in France, they are very numerous and of great richness, but little studied. In order to appreciate these important faunas, we have at our disposal only the old monographs of Reuss (Tortonian), of Busk (Pliocene), and the lists of Seguenza and Neviani (Italy) and the few recent papers of Canu and Duvergier (Miocene of Bordeaux). The faluns of Touraine and the Sahelian of Oran, with a wonderful richness, are known only from the manuscript notes of Canu extracted from a work that may never be published for lack of time and resources.

The American Lower Miocene Tampa and Alum Bluff formations furnish too few bryozoa to help in intercontinental correlation. The following American Miocene strata form two groups. In the first should be

classed the Choptank and Saint Marys formations. They present an association of genera which persist today in the temperate Atlantic. The small number of Recent species present indicates a relative antiquity for the formation, but, with the bryozoa only, it is impossible to fix the age. Possibly the association of *Cupularia* and *Theonoa*, observed in Touraine, authorizes us at least to class the Saint Marys formation near the Helvetian.

In the second group must be classed the Bowden horizon, the Yorktown formation, the Duplin marl, and the Choctawhatchee marl. Their faunas are tropical or subtropical and are closely related to the Recent fauna of the Gulf of Mexico. They are in continual regression toward the south because of constant rising of the American continent. *Velumella, Floridina, Steganoporella, Metrarabdotos,* and *Hippaliosina* are the most characteristic genera.

The Bowden horizon was considered for a long time in Europe as the equivalent of the Lower Miocene (Burdigalian). We have observed here 52 species, in which 16 are Recent (32 per cent), thus indicating a more recent division of the Miocene.

The faunules collected in the other formations are of unequal value and little comparable among themselves. Nevertheless, in applying the usual method of enumeration we have constructed the following small table:

	Species observed.	Recent species.	Percentage.
Choctawhatchee marl	22	8	36
Duplin marl	50	17	34
Yorktown formation	32	9	28

Although this method is often of little value, in this case it confirms the superposition recognized by the geologists; but it is absolutely impossible to establish any synchronism whatever with the European deposits formed in a much colder zone. The species pass easily from one stage to another, even into the Pliocene, and there is apparently little arrest in sedimentation.

Pliocene Bryozoa

From the Pliocene we have material from three localities only. They have given only 36 species. This fauna can not be compared, however, with the Miocene, which here yielded more than a hundred species. According to the percentage of Recent species, the Waccamaw marl of the Pliocene is, perhaps, the inferior horizon, and the Caloosahatchie marl, especially as developed in Munroe County, Florida, is doubtless at the top.

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AMERICAN AND EUROPEAN EOCENE AND OLIGOCENE MOLLUSKS *

BY C. WYTHE COOKE

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

The basis for the comparison of American with European lower Tertiary mollusks has been the following: For America, the collections in the United States National Museum and the monographs of G. D. Harris[1] on the Midway and "Lignitic" (Wilcox group) mollusks and on the "Pelecypoda of the Saint Maurice and Claiborne stages." For Europe, the works of Briart and Cornet[2] and of Cossmann[3] on the Montian; of Cossmann and Pissarro[4] on the Eocene of the Paris Basin; of Oppenheim[5] on the Priabonian of Italy; of von Koenen[6] on the lower and middle Oligocene of North Germany; of Speyer[7] on the upper Oligocene of North Germany; and the rather meager collections of European fossils in the United States National Museum. Few direct comparisons of shell

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with shell have been possible; more often shells have been matched with figures, or simply plate with plate.

Eocene

Midway group

The mollusks of the Midway group show little in common with any European stage. As the Midway is the lowest group of the eastern American Eocene, one would naturally look for affinities in the Montian of Europe. The Midway and the Montian each contain one species of *Calyptraphorus,* but the European form appears to be closer to the Claiborne and Jackson species than to the Midway. The Montian *Plejona,* likewise (which appears to range throughout the European Eocene), is very close to, perhaps identical with, the Claiborne and Jackson species, but very different from any Midway form. The presence of several long-ranging Eocene species in the Montian makes its fauna appear younger than that of the Midway. The absence, so far as known, of *Cucullæa* from the Montian and the presence of a very common species in the Midway also suggest a greater age for the Midway, but there is a *Cucullæa* in the Thanetian.

Wilcox group

The Wilcox group is a more promising field for investigation. Shells from the Bashi formation (near the top of the Wilcox group) are identified by Harris as *Amussium squamulum* (Lamarck), a European species found in the Ypresian and Lutetian. This species occurs also in the Wilcox of Texas. One of the most characteristic mollusks of the Wilcox group is *Plejona tuomeyi* (Conrad). The European analogue of this species is *P. depressa* (Lamarck) from the Ypresian and Lutetian, and especially the calloused ancestral variety from the Thanetian.[8] An oyster from the Thanetian also resembles one of the Wilcox oysters.

Claiborne group

The aspect of the Claiborne fauna is very similar to that of the middle and upper Eocene of the Paris Basin. In Ameirca the first extensive development of *Trinacria* is in the Claiborne, with 11 species. Ten species of this genus are known in the Eocene of the Paris Basin—6 in the Bartonian, 4 in the Lutetian, 3 in the Ypresian, and 1 in the Thanetian. The greatest development of *Venericardia* in America took place in the Claiborne, with about 11 species. Cossmann and Pissarro figure 27 species from the Paris Basin—10 from the Bartonian, 14 from the Lutetian,

? from the Ypresian, and 3 from the Thanetian. *Pholadomya claibornensis* Aldrich looks very much like the figure of *P. virgulosa* Sowerby from the Ypresian.

JACKSON FORMATION

The evidence furnished by the mollusks on the correlation of the Jacksonian is less satisfactory than that of other organisms, but such as there is corroborates the reference of the Jackson to the Priabonian. *Limopsis radiatus,* a common Jackson bivalve, is similar to, but not identical with, a Priabonian species. Casts of a large *Pleurotomaria* from the Castle Hayne limestone of North Carolina are comparable to Italian species, but obviously different. *Velates grandis* (Cooke) from the Saint Bartholomew and Ocala limestones is closely related to *Velates schmidelianus* Chemnitz. The latter species in the Paris Basin ranges from the Thanetian to the Lutetian, but in Italy it is widely distributed in the Priabonian.

OLIGOCENE

An important tie point in the correlation of the American and European formations is the faunal break between the Eocene and the Oligocene. Less than 9 per cent of the mollusks in the Red Bluff clay (lower Oligocene) are survivors from the Eocene, and the proportion for the entire Vicksburg group is considerably less. Fewer than 5 per cent of the mollusks in the large Sannoissian fauna are Eocene species. Both above and below this break the generic assemblages on both sides of the Atlantic are similar.

Several similar or identical species occur in Oligocene deposits on both sides of the Atlantic, but, although they are characteristic Oligocene species, their range within the Oligocene is too wide to be of much assistance in close correlation. Two species of *Latirus, L. protractus* and *L. perexilis,* both of which range through the Vicksburg group and are present also in the Alazan formation of Mexico, which is of Vicksburg age, are very similar to species in the Oligocene of North Germany.

PROBLEM OF FACIES

Comparison of faunas in widely separated regions, such as the opposite sides of the Atlantic, or even in adjacent areas, such as the Gulf Coastal Plain, Florida, and the Atlantic Coastal Plain north of Florida, is complicated by the problem of facies. Different ecologic conditions may cause contemporaneous faunas to assume very different aspects and, con-

versely, faunas of similar facies but widely separated in time may present very deceptive resemblances. As late as 1915, no one suspected that the Ocala limestone, until then placed at the top of the Vicksburg group, is as old as the Jackson formation of Mississippi; and not until 1923 was it discovered that the so-called lower Chattahoochee coral reef at Bainbridge, Georgia, and the contemporaneous Antigua limestone are of Glendon, or middle Vicksburg, age. In the Eocene of America there is no great development of the Cerithiums, such as characterized the Lutetian of the Paris Basin. There are some species, to be sure, in nearly every formation, from the Clayton Midway to the Saint Bartholomew Jacksonian; but the earliest horizon in America containing many Cerithiums is the Middle Oligocene Glendon formation of Georgia.

Summary

To sum up, the Eocene mollusks as a whole and the Oligocene mollusks as a whole correlate satisfactorily with the Eocene and the Oligocene mollusks on the opposite side of the Atlantic, and the break between the Eocene and the Oligocene is of the same order of magnitude on both sides. In their broader aspects the early, middle, and late Eocene of America agree with the corresponding divisions in Europe, and the resemblance becomes more pronounced with time. Taking into account only our knowledge of the mollusks, precise correlations of formation with formation are not yet practicable.

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CORRELATION OF EUROPEAN AND AMERICAN TERTIARY FORMATIONS

Compiled by C. Wythe Cooke

	EUROPE	UNITED STATES		WEST INDIES AND MEXICO
PLIOCENE	Astian		Caloosahatchee marl	
	Plaisancian		Waccamaw marl	Marine deposits in Haiti
MIOCENE	Pontian	Chesapeake group	Yorktown, Duplin, and Choctawhatchee forms.	Cerros de Sal formation (Dominican Republic)
	Sarmatian		Saint Marys formation	
	Tortonian		Choptank formation	
	Helvetian		Calvert formation	Bowden formation (Jamaica)
		Alum Bluff formation	Shoal River marl	
	Langhian (upper) (Burdigalian)		Oak Grove sand	Cercado formation (Dominican Republic)
	Langhian (lower)		Chipola marl	Thomonde formation (Haiti)
	Aquitanian		Tampa formation	Anguilla formation
OLIGOCENE	Chattian	Vicksburg group	Byram marl	Antigua formation (upper)
	Rupelian		Glendon formation	Antigua formation (lower)
	Sannoisian (Lattorfian)		Marianna limestone	Alazan formation (Mexico)
EOCENE	Ludian		Jacksonian	Saint Bartholomew limestone
	Priabonian			
	Bartonian			
	Auversian		Claiborne group	Yellow limestone (Jamaica)
	Lutetian			
	Ypresian			
	Sparnacian		Wilcox group	Formations at Soldado Rock, Trinidad
	Thanetian			
	Montian		Midway group	

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COASTAL PLAIN AND EUROPEAN MIOCENE AND PLIOCENE MOLLUSKS[1]

BY JULIA GARDNER

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[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formation of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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Introduction

The correlation of the later marine Tertiaries of the Aflantic Coastal Plain and Gulf is obscured by the absence of a good standard section of marine deposits in warm temperate Europe. The European boreal faunas are well developed, and the Mediterranean, but the temperate and warm temperate faunas, which would be most closely comparable to the majority of those of the Atlantic and Gulf provinces, are represented largely by continental, fluviatile, or lacustrine assemblages.

Aquitanian Question of the Atlantic Coastal Plain

General statement

A discussion of the Aquitanian question is quite beyond the limits of this paper. The Aquitanian in Europe ushered in one of the most momentous diastrophic movements in the history of the world. In America, in the Gulf province, the orderly deposition of limestones, marls, and sands continued, with no conspicuous interruption, from the close of the Vicksburg to the close of the Alum Bluff. This long period of gradual transition, combined with the very marked faunal and stratigraphic hiatus at the top of the Alum Bluff, suggested the major break at the end of that epoch. The Oligocene age of most of the southern North American deposits now referred to the Lower Miocene was accepted with little opposition until the latter part of the last decade.

The discovery of Miocene vertebrate remains in the fuller's earth beds of the Alum Bluff in 1916 and the recent intensive studies of the Miocene tropical and subtropical faunas, particularly of the lower invertebrates, both in this country and in Europe, have proved the fallacy of the older correlation. The Tampa formation, which has lately been admitted to the Miocene, is correlated with the Aquitanian because of the position in the section rather than from any marked resemblance to the Aquitanian of Europe, which is, in the main, fresh or brackish water.

Relation between the faunas of the Tampa and Chipola formations

The mollusca of the Tampa share the general character of the succeeding Chipola. However, the similarity is, for the most part, generic rather than specific. Three hundred and twelve Tampa species have been recognized, but of these only a little more than 4 per cent, most of them of little stratigraphic significance, are identical with those of the Chipola formation. The earlier results gave an average of more than

16 per cent, and the fact that there are so many forms that are readily confused indicates the strong general resemblance between the Tampa and the Chipola.

There is no evidence of any factor other than time which would account for the slight, though constant, differences between the two faunas. Both the Tampa and the succeeding Chipola indicate a shallow subtropical sea with no diastrophic movements of consequence. However, the Chipola was in some localities a period of transgression, and it certainly was a period of rapid faunal evolution.

The distribution of the later Tertiaries is largely concealed in the Gulf province by the heavy Pleistocene cover, but the Chipola has been recognized on the surface from the vicinity of Porters Landing, on the Savannah River, Effingham County, Georgia, to the Tampico area, and in well borings as war west as eastern Texas.

Correlation of the Chipola Formation with the European Section

The character of the lower Chipola along the Chipola and the Apalachicola rivers is very similar to that of the typical lower Langhian of Europe—a so-called *falun,* a coquina with a sandy matrix. The Langhian, like the Aquitanian, is well developed in the Garonne basin and offers one of the most satisfactory faunas for comparative study. All of the lower Miocene molluscan faunas have been exhaustively treated by Cossmann and Peyrot[2] in a series of recent monographs.

The lower Chipola fauna is more directly comparable to the European than any other Tertiary fauna of the middle Atlantic coast or Gulf.

The Chipola was, apparently, a period of unstable equilibrium. A number of new lines of development were being tried, and this, together with the favorable living conditions, produced a heterogeneous fauna. The number of peculiar species is very large, approximately 75 per cent. Though there are probably no species identical on the two sides of the Atlantic, there are many which bear a striking general resemblance, and in the majority of the groups the generic likeness is notable. This is particularly true among the taxodonts.

Nearly all of the subgenera of the south European *Arca,* with the exception of the deep-water forms, occur in the Chipola. It is possible that a slightly less shallow, and consequently cooler, sea may account for the greater development of *Astarte* in the fauna of southern Europe.

[2] M. Cossmann and A. Peyrot: Conchologie néogénique de l'Aquitaine, vol. 1, 1909-1912; vol. 2, 1912-1914; vol. 3, 1917-1919; vol. 4, 1922.

This characteristically cold water genus is, apparently, without representation in the Chipola.

Cardita and *Venericardia* are strikingly similar in their general development. Though never a dominant factor, the group is widely distributed in the warm waters on both sides of the Atlantic. The close relationship between *Cardita* (*Carditamera*) *apotegea* from the Chipola and *Cardita* (*Carditamera*) *elongata* (Aquitanian to Tortonian) of the Gironde is obvious. Unfortunately, the species with a wide geographic distribution are, as a rule, the less sensitive forms, with a wide range in time.

The Lucinoids also show a striking parallelism during the lower Langhian. The true Lucinas are, in the Gironde, according to Cossmann and Peyrot, represented by *Loripinus* Monterosato—a group which differs from *Lucina* mainly in the character of the ligament attachment. There is certainly a remarkable superficial likeness between *Lucina janus* Dall and *Lucina* (*Loripinus*) *globulosa* Deshayes from the Aquitanian and Langhian, between *Miltha chipolana* Dall and *Miltha multilamellata* Deshayes from the Aquitanian, between *Here glenni* Dall from the Chipola, and *Linga columbella* Lamarck from the Aquitanian to the Helvetian.

Possibly the burrowing and parasitic habits of many of the Leptonacea may account for the many resemblances exhibited in species of this group widely separated geographically. Among the most striking is that shown by *Scacchia actinophora* Dall and *Scacchia cardintorta* Cossmann from the Aquitanian and Langhian. The American and European *Cardia*, however, within the areas under consideration, have much less in common. We have nothing closely comparable to *Ringicardium* so prominent in the Gironde fauna nor to the curious *Discors*.

Lævicardium is much more prominent in the European fauna than in the American, while *Fragum* has not been recognized by Cossmann and Peyrot. There is a rather marked difference, too, in the relative prominence of the Venerid genera in the two faunas. The well characterized little *Transenella* is apparently restricted to the Atlantic; our American *Macrocallista* is represented by the so-called *Callista*—a heavier, concentrically sculptured shell. *Chione* (*Lirophora*) is unknown in the Gironde. The outstanding differences in the Venerid faunas of the Lower Miocene of Europe and America are, in the main, the outstanding differences in the Venerids of the Recent faunas. The fact that these differences were already established in one of the most highly organized of the molluscan groups is indicative of the modernity already assumed in both.

The persistence of certain types of bizarre sculpture in both the American and European representatives is worthy of note. Among these may be mentioned the oblique sculpture developed by *Divaricella, Strigilla,* and *Solenocurtus* (*Macha*). All of these genera are represented by species on both sides of the Atlantic which strongly resemble each other. The Chipola is a dominantly gastropod fauna, but the soft parts are less intimately related to the hard than they are in the pelecypods, and it is more difficult to properly evaluate the resemblances and differences. In the main, the general types are similar. *Orthaulax,* one of the most significant genera in the Chipola fauna, is a bizarre and consequently short-lived and diagnostic genus, restricted to the American faunas.

Correlation of the Oak Grove Formation with the European Section

General statement

The Langhian of Europe was, for the most part, a period of transgression. In southwestern France the temporary retreat of the sea during the middle Langhian is indicated by the lacustrine deposits. In Florida, however, the Chipola apparently marks the maximum transgression as well as the closest approach to tropical conditions.

Environmental conditions during the Oak Grove epoch

The original distribution of the Alum Bluff is very imperfectly known, but it is probable that the close of the Chipola is marked by a decided regression and by a lowering of the temperature to a degree sufficient to materially affect the animal life. The radical fall in temperature at the close of the Alum Bluff is foreshadowed in the fauna of the grayish green Oak Grove sand. The species recognized in the Oak Grove number less than half those listed from the Chipola, but the number of individuals is increased. The appearance of the large fulguroids and of *Pecten* (*Chalmys*) closely allied to *Pecten madisonius* Conrad are suggestive of the Chesapeake Miocene.

The conspicuously abundant and ubiquitous forms, such as *Turritella alcida* Dall, *Scapharca dodona* Dall, and *Chione glyptocyma* Dall, are all of them newcomers, and with the exception of *Cardium taphrium* Dall, which is present in the Shoal River, have left no trace in any later formation. They were extraordinarily well adapted to Oak Grove conditions, but were too highly modified to change with the changing environment.

The Oak Grove does not share with the Chipola certain archaic types, such as *Orthaulax.* Like the Chipola, however, it is correlated with the

Langhian of Europe and finds its closest affinity in the fauna of the Garonne basin. There is also a strong general resemblance between the Oak Grove and certain phases of the Miocene of Eggenburg, in the Vienna basin.[3]

Correlation of the Shoal River Formation

General statement

The Shoal River fauna is more complex than either that of the Chipola or of the Oak Grove. The number of recognized species is increased to nearly 300, of which over 200 are restricted to the single formation, and several of them are as prolific as the prolific species of the Oak Grove.

Relation between the faunas of the Shoal River and the Gatun formations

The introduction of the new element results in a fauna bearing a decided resemblance to the Gatun fauna of the Canal Zone. It is difficult to express the resemblance in percentages, for the two faunas have been so unevenly treated, but to any one who is using them as study faunas the constant repetition of likenesses in general characters and in detailed is very significant. This close relationship between the Gatun and the Shoal River must be explained either by a return to warmer water conditions and a consequent invasion of a southern fauna toward the close of the Alum Bluff or by the proximate synchroneity of the Shoal River and the Gatun.

The Shoal River, however, contains certain cooler water elements, such as four species of *Astarte,* which makes it difficult to accept the assumption of a southern current during that time. Furthermore, most of the elements which are introduced into the fauna have not been recognized in the earlier Miocene. It is possible, of course, that this common fauna may later be found in the older beds, but from the evidence now available it is hard to believe that the Shoal River and the Gatun can be far removed in time. The solution of this problem may, perhaps, be deferred until the neglected Gatun is better known.

It is most unfortunate that our knowledge of the field relations of the Alum Bluff is so sketchy. Possibly the Shoal River is represented in the section at Alum Bluff by the erosion unconformity. In the uncertain state of our knowledge, it seems best, perhaps, to correlate the Shoal River with that fauna to which it shows the most significant relationship—the Gatun—and to place it with the Gatun, tentatively at the base of the

[3] Franz X. Schaffer: Das Miocän von Eggenburg, Abhand. K. K. Geol. Reich., Band 22, Heft 1, 2, 4, 1910-1914.

Middle Miocene rather than at the top of the Lower. The correlation with the European deposits must be governed by the relative position in the American section, for there is no European fauna so closely allied that a direct correlation can be made.

RELATION BETWEEN THE SHOAL RIVER AND THE CALVERT FORMATIONS

The same difficulty is experienced in determining the relation to the Chesapeake faunas. The Calvert, the lowest formation of the Chesapeake group, has not been recognized south of Virginia. It is possible that the difference in latitude is sufficient to account for the absence of any but the most general resemblance between the Calvert and the Shoal River. The possibility of following the paleobotanical evidence and correlating the Calvert with the Tortonian suggests itself. The Choptank is the sandy bottom phase of the sedimentary cycle in which the Calvert was deposited and is the biologic expression of the physical conditions attending its close. There are no described European faunas that offer any convincing resemblance to those of the lower part of the Chesapeake group. The Saint Marys fauna, though similar to those of the lower Chesapeake in the general make-up, is differentiated from them by an influx of new forms and by the absence of those species peculiar to the cooler waters of the Calvert and the sands of the Choptank.

Correlation of the Chesapeake Group with the European Section

GENERAL STATEMENT

The fauna of the Middle Miocene of North Germany, particularly of the Holstein[4] beds, offers a basis for a general comparison. The Holstein Sea, however, must have been somewhat warmer than the Chesapeake, for the fauna includes several species of *Murex* and *Fusus, Cancellaria* in abundance, and only a single described species of *Astarte*. The most striking specific resemblance is that between *Stenomphalus wiechmanni* von Koenen from the Holstein and *Ecphora quadricostata* Say from the Chesapeake.

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[4] A. von Koenen: Miocän Nord-Deutschlands und seine Mollusken-Fauna. Schrift. der Gesell. zu Beförd der gesammten Naturwiss. zu Marburg. Band 10, Abhand. 3, 1872, pp. 1-262, pls. 1-3.

A. von Koenen: Die Gastropoda holostomata und tectibranchiata, Cephalopoda und Pteropoda des Norddeutschen Miocän. Neues Jahr. für Min., Geol., und Pal. Bell., Band 2, 1883, pp. 223-365, pls. 5-7.

C. Gottsche: Die Mollusken-Fauna des Holsteiner Gesteins, Abhand. aus dem Gebiete der Naturwissen. herausgegeben vom Naturwissen. Ver. in Hamburg. Band X, Festschrift, 1887, pp. 1-14.

RELATION BETWEEN THE FAUNAS OF THE YORKTOWN AND DUPLIN FORMATIONS

The change in the paleontologic character at the close of the Saint Marys is much more significant than that preceding it. Although the percentage of new forms in the overlying Yorktown is not remarkably large, the general facies shows a distinct advance over the Saint Marys. The more primitive types, such as *Ostrea compressirostra* Say, have become extinct or show an abrupt decrease in prominence, while a number of the more advanced types, such as *Scapharca lienosa* Say, which constitute conspicuous elements in the later faunas, are initiated at this horizon.

Correlation of the Duplin and Choctawhatchee Formations with the European Section

The views advanced by Dall on the approximate synchroneity of the Yorktown and Duplin faunas have been verified by subsequent investigations. He suggested the elimination of the cool, inshore current of the earlier Miocene and the reestablishment of a Tertiary Gulf Stream as the probable cause of the subtropical aspect of the Duplin fauna.

The vicinity of the Hatteras axis was, apparently, in Tertiary times, as it is in Recent, a critical area in the distribution of the marine life, and in a general way it has marked for geological ages the southernmost extension of the northern forms and the northernmost extension of the southern. Both the Yorktown and the Duplin, together with the Jacksonville and Choctawhatchee formations of Florida, are placed at the top of the Miocene as the time equivalents of the Pontien and possibly, in part, of the Sarmatian and Tortonian. The Pontien represents throughout southwestern Europe a period of marine regression. The faunas are, for the most part, brackish water, lacustrine, and fluviatile. The *Congeria* beds, which are typical for the period, have no close equivalent on this side of the Atlantic.

Correlation of the Waccamaw Marl with the European Section

GENERAL STATEMENT

The time interval between the Duplin and the Waccamaw is probably slight. Both of these faunas contain a larger percentage of Floridian species than does the Recent North Carolina fauna.

ENVIRONMENTAL CONDITIONS ATTENDING THE LATE MIOCENE AND EARLY PLIOCENE ALONG THE VIRGINIA-NORTH CAROLINA COAST

It is probable that the late Miocene and early Pliocene Gulf Stream hugged the shore even more closely than does the present Gulf Stream, swinging off to open sea in the vicinity of Hatteras, so that its influence on the Yorktown fauna was negligible. Even so early as the late Miocene and early Pliocene, there is every reason to believe that present-day conditions had been approximated along the east coast.

CORRELATION OF THE PLIOCENE FAUNAS OF PENINSULAR FLORIDA WITH THE EUROPEAN SECTION

. The faunas of southern Florida indicate an appreciable advance over the Waccamaw. It is probable that the Caloosahatchee represent the Middle Pliocene and is the equivalent in part of the Astian, while the uppermost Pliocene is possibly represented by some of the smaller, little-known Floridian assemblages. These will find their closest equivalents in the faunas of the embayments of the Mediterranean, particularly in the Venetian[5] and Sicilian basins. The differences between these Pliocene faunas of Florida and of the Mediterranean are in the main those that exist between the Recent Floridian and Mediterranean faunas.

[5] Giuseppi Stefanini: Il Neogene Veneto. Monografia sui Terreni Terziari del Veneto, Padova: R. Universita, 1st Geol. Mem., vol. 3, pt. 2, 1915, pp. 337-624, plates 10-17, 34 text figures.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

WEST INDIAN, CENTRAL AMERICAN, AND EUROPEAN MIOCENE AND PLIOCENE MOLLUSKS[1]

BY WENDELL P. WOODRING

(*Read before the Paleontological Society December 27, 1923*)

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INTRODUCTION

The Miocene and Pliocene faunas of the West Indies and Central America should be compared only with European faunas that lived under essentially similar conditions. These American faunas, with the exception of a supplementary Mexican fauna, are almost purely tropical, according to the distribution of their living genera. The Miocene and Pliocene faunas of the Mediterranean region and the Miocene faunas of Aquitaine, which most closely resemble these American faunas, include

[1] This paper is one of the series composing a "Symposium on the correlation of the Tertiary formations of southeastern North America, Central America, and the West Indies with the Tertiary formations of Europe."

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the following temperate genera:[2] *Mytilus* (*Mytilus*), *Astarte*, *Cardium* (*Cerastoderma*), *Macoma* (*Macoma*), *Solen* (*Solen*), *Ensis*, *Saxicava*, and *Aporrhais*. None of these genera are in any of the West Indian Tertiary or living shallow-water faunas. All except *Aporrhais* are common in the Tertiary and living faunas of the Atlantic coast of the United States. *Aporrhais* has not been found in the Tertiary faunas of the

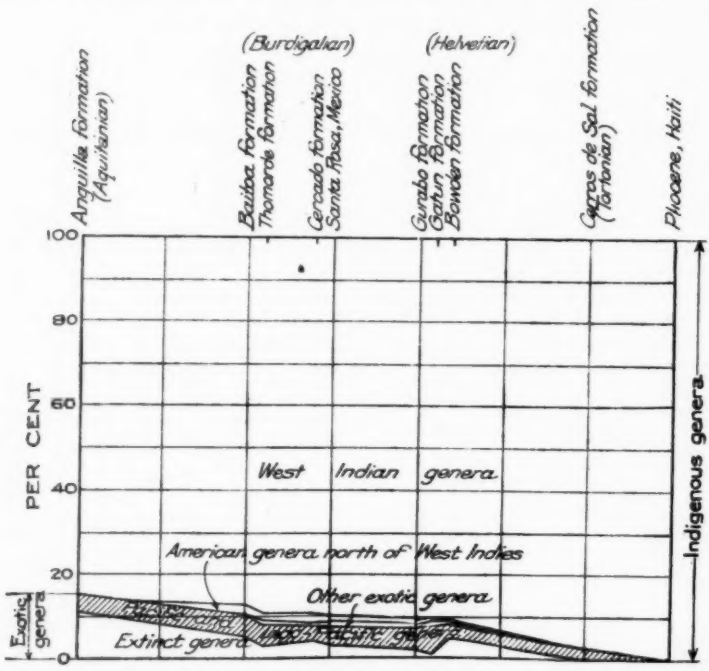

FIGURE 1.—*Graph showing approximate Composition of West Indian and Central American Miocene and Pliocene Faunas*

Atlantic States, but is living in temperate waters on both sides of the Atlantic. Although these European faunas are not strictly tropical, they resemble the West Indian faunas in many features. So far as temperature is concerned, they are comparable in the same sense that the West Indian faunas are comparable to a subtropical fauna on the American mainland.

[2] In this paper genus is used instead of continually repeating genus, subgenus, and section.

All the West Indian and European faunas considered in this paper are essentially shallow-water faunas. Slight recognizable differences in depth are disregarded. The presence of some genera, such as *Tindaria*, *Bathyarca*, and *Seguenzia*, which are persistent deep-water dwellers in the present seas, is puzzling. Collections of predominantly shallow-water mollusks including these genera represent different bathymetric zones, or during Tertiary time they lived in shallower water. Bottom conditions are disregarded because not enough is known about them for the Tertiary faunas. Faunas of 500 or 600 species, like the Miocene West Indian faunas, or of 1,000 or more species, like those from the Miocene and Pliocene of the Mediterranean region, probably are not homogeneous. It seems unreasonable to believe that so many species could live on the same kind of bottom. Large collections from even one locality may include specimens washed from different kinds of bottoms.

Superspecific group—genera, subgenera, and sections—for convenience called genera, are used in comparing the West Indian and south European faunas. The first appearance of a genus in the two regions is a significant feature, provided there is a possibility of free migration and a suitable habitat. Even when unrestricted migration is possible, the dispersal of a genus depends on the length of the swimming larval stage. Many genera of marine mollusks have no swimming larval stage and their distribution is essentially provincial. This feature has been discussed by Doctor Vaughan in the introductory paper of this symposium.

Composition of West Indian and Central American Miocene and Pliocene Faunas

The percentage composition of the West Indian and Central American Miocene and Pliocene faunas, based on the genera, is graphically represented in figure 1. The relative time spacing in the graph is arbitrary. Several families of gastropods—Turritidæ (= Pleurotomidæ), Epitomiidæ (= Scalidæ), Melanellidæ, and Pyramidellidæ—and the scaphopods were not used in preparing the graphs, as their nomenclature is too chaotic. The graph is only a crude approximation of the actual composition of the faunas. Most of them have not been adequately studied and not all are comparable in size or in living conditions. Despite these unfavorable features, the graph clearly shows the principal elements of the faunas. It shows that they are predominantly West Indian. Even in the oldest fauna, 84.6 per cent of the genera are now living in West Indian waters. The percentage of living West Indian genera steadily, but not uniformly, increases as the age decreases.

The relatively large percentage of genera now living in the Pacific or the Indo-Pacific region is a striking feature of the Miocene faunas. These genera are as follows:

Nucula (Acila)
Placunanomia
Julia
Cardium (Lophocardium)
Clementia
Cooperella
Mactra (Harvella)
Jouannetia
Terebra (Terebra)
Cancellaria (Aphera)
Cancellaria (Narona)
Peristernia
Solenosteira
Metula
Northia
Columbella (Meta)
Strombina
Cymia
Malea
Pustularia
Cirsochilus

The percentage of these exotic genera decreases rather uniformly, but there is an apparent increase in the fauna of the Gatun formation of the Canal Zone and Costa Rica. If this actually is an increase, its significance is not known. The small mollusks of the Gatun formation have so far been neglected. It may confidently be predicted that when they are studied the percentage of exotic genera will decrease, as most of the exotic genera are large.

The percentage of extinct genera also decreases rather uniformly, except for the fauna of the Bowden formation of Jamaica, which has been more exhaustively studied than any other large fauna shown in the graph. The extinct genera, exclusive of new extinct genera in the Bowden formation, are as follows:

Spirulirostra
Barbatia (Obliquarca)
Noetia (Sheldonella)
Cuspidaria (Bowdenia)
Neæromya
Alveinus
Corbula (Bothrocorbula)
Strombinella
Metulella
Orthaulax
Solariorbis
Ampullina
Ampullinopsis

Genera that are not living in West Indian waters, though not confined to the Pacific (other exotic genera of figure 1), are a minor feature. They include *Cardita* (*Cardita*), *Cardium* (*Cardium*), *Halia*, and *Euthria*. These exotic genera are common fossils in the Mediterranean Miocene and Pliocene deposits.

According to available records, the following living American genera have not been discovered in West Indian waters:

Venericardia (Pleuromeris)	Alectrion (Tritia) [called Nassa (Uzita) by some Europeans]
Montacuta	
Sportella	Sycotypus
	Amauropsis

Only one of these genera—*Amauropsis*—is not recorded from the Gulf of Mexico or the east coast of Florida, and it alone detracts from the tropical aspect of the Tertiary faunas.

The percentage of exotic and extinct genera is significant in determining the age of a West Indian Miocene or Pliocene fauna. This standard can be used only for large faunas. If faunas that lived under similar conditions were completely studied they probably would show smoother curves in a graph like figure 1. Under these favorable, but perhaps unattainable, conditions it might be possible to determine the age of a fauna by simply plotting the percentage composition.

Composition of South European Miocene and Pliocene Faunas

PIEDMONT BASIN

The faunas of the richly fossiliferous beds in the classic Piedmont basin of Italy are used as representative of the Mediterranean Miocene and Pliocene. The type localities of the Tortonian, Plaisancian, and Astian stages are in the Piedmont basin. The mollusks from these deposits have been described in the monumental series of monographs begun by Bellardi and completed by Sacco.[3] The marine deposits carrying large shallow-water faunas are of Helvetian, Tortonian, Plaisancian, and Astian age. The Aquitanian deposits of the Venetian basin (Schio beds)[4] are used to supplement the Miocene faunas of the Piedmont basin. Apparently there are no large shallow-water Burdigalian faunas in these two Italian basins comparable to the West Indian faunas.

Figure 2 is a graphic representation of the percentage composition of the faunas from the Piedmont basin. This graph shows remarkably smooth curves, although the data on which it is based are less reliable than in figure 1, as I naturally do not know the European faunas so well as the West Indian. The curves between the Astian stage and the living fauna would be more irregular if the Quaternary faunas of the Sicilian, Milazzian, Tyrrhenian, and Monasterian stages were plotted.

[3] L. Bellardi and F. Sacco: I molluschi dei terreni terziarii del Piemonte e della Liguria, 30 parts. Torino, 1872-1904. Bellardi is the author of the first five parts and Sacco of all the others.

[4] P. Oppenheim: Ueber die Ueberkippung von S. Orso, das Tertiär des Tretto und Fauna wie Stellung der Schioschichten. Deutsch. Geol. Gesell. Zeitschr., vol. 55, 1903, pp. 98-235, pls. 8-10.

The most striking feature shown by figure 2, as compared to figure 1, is the large percentage of exotic genera. These Miocene and Pliocene faunas are very different in some features from the living Mediterranean fauna, as has been known ever since the Mediterranean Tertiary faunas

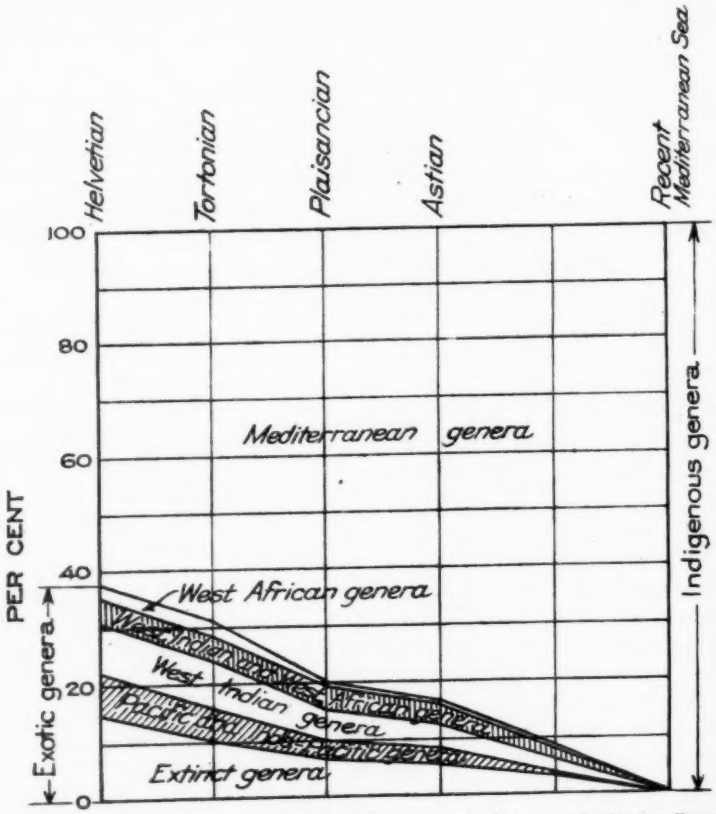

FIGURE 2.—*Graph showing approximate Composition of Miocene and Pliocene Faunas of Piedmont Basin, Italy*

were first studied. The Mediterranean Sea has had a complicated geologic history and its living fauna is due chiefly to invasions of a temperate fauna from the Atlantic in Quaternary time. Some genera of the displaced Tertiary fauna are now living along the west African coast; others are living in the West Indian region; others are confined to the

Pacific and Indo-Pacific regions. The percentage of exotic genera decreases steadily, but not uniformly, as the age decreases.

The graph shows that the Mediterranean Miocene and Pliocene faunas have a relatively large percentage of genera that are not living now in any European or west African waters, but are living in the West Indian region. These genera, some of which are living also in the Pacific or Indo-Pacific region, are as follows:

Leda (Jupiteria)
Neilo
Neilo (Neilonella)
Tindaria
Amusium
Plicatula
Cuspidaria (Cardiomya)
Deuteromya (= Dimya)
Modiolus (Brachydontes)
Phacoides (Cardiolucina) [included in Phacoides (Cavilucina) by Americans]
Phacoides (Pleurolucina) [Phacoides (Here) miobarbieri Sacco probably is a Pleurolucina]
Protocardia (Nemocardium)
Rocellaria (Spengleria) [= Gastrochæna Spengleria)]
Martesia
Engina
Distorsio (called Persona by most Europeans)
Bursa (called Apollon by most Europeans)
Gutturnium (called Ranularia by most Europeans)
Phos
Xancus (called Turbinella by most Europeans)
Coralliophila
Ancillaria
Lyria
Columbella (Conidea)
Sconsia
Morum (Oniscidia)
Ficus (called Ficula or Pyrula by most Europeans)
Terebra (Fusoterebra)
Conus (several groups)
Erato
Rissoina (Rissolina)
Rissoina (Zebinella)
Vanikoro
Xenophora (Tugurium)
Neritina (Puperita)
Modulus
Pleurotomaria
Zeidora
Subemarginula
Rimula
Sabatia

A smaller percentage of genera are now living in the West Indies and along the west African coast, but not in European waters. Some of these genera are living also in the Pacific or Indo-Pacific region. They are as follows:

Isognomon (usually called Perna or Pedalion)
Crassatellites (called Crassatella by most Europeans)
Phacoides (Linga) [included in Phacoides (Here) by Americans]
Codakia (Codakia)
Olivella
Latirus
Cassis
Conus (probably several groups)
Strombus
Cancellaria (Trigonostoma)
Seila

Metis (called Capsa by most Europeans)
Murex (Pteronotus)
Melongena
Oliva
Amalthea
Chelica (called Mitrularia by most Europeans)
Nerita
Acteocina

As most of the genera in the two preceding lists are common West Indian Miocene fossils, the faunas from these two regions are similar. So far as these numerous genera are concerned, the Mediterranean Miocene and Pliocene faunas are more similar to the living West Indian fauna than to the living Mediterranean.

The following genera are living on the west African coast. Some of them range northward to Spain and the Azores; others are living also in the Pacific or Indo-Pacific region:

Vitularia
Pusionella
Halia
Cancellaria (Solatia)
Harpa
Tympanotomus
Mesalia
Protoma
Oxystele

The Mediterranean faunas also resemble the West Indian faunas in having genera that are now confined to the Pacific or Indo-Pacific region. The percentage of these exotic genera is higher than in the West Indian faunas that seem to be of the same age. The Pacific and Indo-Pacific genera are as follows:

Septifer
Discors
Isocardia (Miocardia)
Cardilia
Jouannetia
Clavellithes (called Clavella by most Europeans)
Cominella
Volema (called Pugilina by most Europeans)
Latrunculus
Iopas
Acanthina
Tudicla
Latirus (Dolicholatirus)
Mitra (Mitra)
Mitra (Thala)
Malea
Rostellaria
Rimella
Pustularia
Erato (Eratopsis)
Cancellaria (Scalptia)
Cancellaria (Merica)
Cancellaria (Ventrilia)
Cancellaria (Ovilia)
Cancellaria (Aphera)
Cancellaria (Massyla)
Terebralia
Telescopium
Stossichia
Turritella (Zaria)
Delphinula
Cirsochilus
Scutus
Scurria

Comparison with the list on page 870 show that only 5 of these genera—*Jouannetia, Malea, Pustularia, Cancellaria* (*Aphera*), and *Cirsochilus*—also occur in the West Indian Miocene deposits.

The percentage of extinct genera is greater than in the West Indian faunas. This may be partly due to the more refined separation of superspecific groups by Sacco. The percentage for the West Indian faunas will increase, however, when they are as completely studied as the Mediterranean faunas.

AQUITAINE BASIN

The type localities of the Aquitanian and Burdigalian stages are in Aquitaine, in southwestern France. This basin also contains deposits of Helvetian and Tortonian age. The molluscan fauna of these deposits is being monographed by Cossmann and Peyrot.[5] As their description of the gastropods is not yet complete, only the pelecypods have been used in making comparisons with the West Indian faunas.

The composition of the Miocene faunas of Aquitaine is graphically shown in figure 3. Although figure 2 is based on almost all the mollusks and figure 3 on only the pelecypods, the graphs show essentially the same features. The increase in the percentage of exotic and extinct genera in the Tortonian fauna may not represent an actual increase, as it is only a third as large as the others and therefore is hardly comparable.

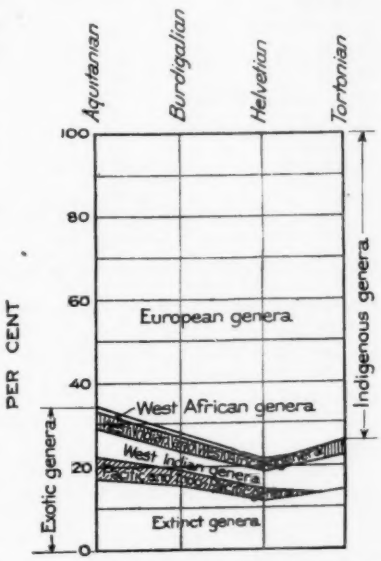

FIGURE 3.—*Graph showing approximate Composition of the Miocene Faunas of Aquitaine Basin, France (based on Pelecypods)*

According to the graphs, the Helvetian fauna of Aquitaine has a smaller percentage of exotic genera than the Helvetian fauna of the Piedmont basin. Some of this difference probably would be eliminated if the graphs were based on similar data.

The exotic genera in the faunas of Aquitaine are listed in the follow-

[5] M. Cossmann and A. Peyrot: Conchologie néogénique de l'Aquitaine, vol. 1, 718 pp., 28 pls., 3 maps, 135 text figs., Bordeaux, 1909-1912; vol. 2, 496 pp., 26 pls., 25 text figs., 1912-1914; vol. 3, 709 pp., 17 pls., 70 text figs., 1917-1919; vol. 4, pt. 1, 321 pp., 7 pls., 1922.

ing lists. Genera living in the West Indies but not in European waters are as follows:

Tindaria
Neilo
Pleurodon (called Nuculina by Cossmann and Peyrot)
Noetia (included in Anadara by Cossmann and Peyrot)
Amusium
Plicatula
Deuteromya (= Dimya)
Carditopsis [a]
Miltha [b]
Diplodonta (Felaniella)
Erycina (Erycina)
Aligena
Phacoides (Cardiolucina) [included in Phacoides (Cavilucina) by Americans]
Protocardia (Nemocardium)
Siliqua [c]
Basterotia
Martesia
Rocellaria (Spengleria) [= Gastrochæna (Spengleria)]

a Bahamas and Bermuda.
b Brazil.
c Atlantic coast of the United States.

The following genera are living in West Indian and west African waters, but not in European waters. Some of these genera, like some in the preceding list, are living also in the Pacific or Indo-Pacific region:

Isognomon (usually called Perna or Pedalion)
Crassatellites (called Crassatella by most Europeans)
Codakia (Codakia)
Phacoides (Linga) [included in Phacoides (Here) by Americans]
Tivela
Metis (called Capsa by most Europeans)
Petricolaria

Genera living along the west African coast, but not in the Mediterranean Sea or in the West Indies, are as follows:

Ungulina
Tugonia
Jouannetia (Triomphalis)

The following genera are confined to the Pacific and Indo-Pacific regions:

Trisidos (called Paralelipipedium by most Europeans)
Julia
Septifer
Galeomma (Thyreopsis)
Discors
Trapezium
Circe
Sunetta (Solanderina)
Phylloda
Jouannetia

Only 5 (*Neilo, Pleurodon, Aligena, Rocellaria* (*Spengleria*), and *Petricolaria*) of the 25 genera in the first two of the preceding lists have not been discovered in Miocene deposits of the West Indies. *Julia* and

Jouannetia, two of the Indo-Pacific genera, occur in the West Indian Miocene.

The preceding European faunas include the type faunas of the Aquitanian, Burdigalian, Tortonian, Plaisance, and Astian stages. In introducing the term Pontilevian for the littoral Helvetian deposits of Touraine, Dollfus and Dautzenberg[6] reject Helvetian because as originally used by Mayer it included all the Miocene. Although this objection is based on valid grounds, the term Helvetian has been restricted and has a definite age significance.

Comparison of West Indian and Central American Faunas with European Faunas

MIOCENE

Aquitanian.—No large fauna of supposed Aquitanian age has been discovered in the West Indies or Central America. Collections in the United States National Museum from the upper part of the Culebra formation of the Canal Zone, which is supposed to be Aquitanian, have not been described. Vaughan[7] has published an incomplete list of mollusks from these deposits, and Brown and Pilsbry[8] described 5 species. These published lists give a wholly inadequate idea of the Culebra fauna.

The Emperador limestone of the Canal Zone also is considered of Aquitanian age. It has a relatively meager molluscan fauna, like other coralliferous limestones, consisting principally of Pectens. Brown and Pilsbry[9] have described most of the Emperador mollusks. Vaughan[10] has listed a few additional undetermined species.

Deposits of supposed Aquitanian age so far examined in the West Indies are coralliferous limestones. Their molluscan fauna is in no way comparable to the Aquitanian fauna of Aquitaine, which contains 219 species of pelecypods. The largest fauna from any of the West Indian deposits, obtained from the Anguilla formation of the Island of Anguilla,

[6] G. F. Dollfus and P. Dautzenberg: Conchyliologie du Miocène moyen du bassin de la Loire. Soc. géol. France Mém. Paléontologie, no. 27, 1902, pp. 7-8.

[7] T. W. Vaughan: The biologic character and geologic correlation of the sedimentary formations of Panama in their relation to the geologic history of Central America and the West Indies. U. S. Nat. Mus. Bull. 103, 1919, pp. 552-553.

[8] A. P. Brown and H. A. Pilsbry: Fauna of the Gatun formation, Isthmus of Panama. II: Acad. Nat. Sci. Philadelphia Proc., vol. 64, 1913, pp. 500-519, pls. 22-26, 5 text figs. The fossils from the upper part of the Culebra formation are listed on page 503 as "species observed in the lignitic layers near Tower N, Las Cascadas."

[9] Idem. The mollusks from the Emperador limestone are listed on page 503 as "species observed in the Pecten bed at Tower N, Las Cascadas."

[10] Loc. cit., p. 558.

has been described by Cooke.[11] The Anguilla fauna consists of 40 species. The earliest appearance of genera is the only basis of comparison with the Aquitanian fauna. Both faunas contain the earliest *Metis* (called *Capsa* by most Europeans) known in European and American Tertiary deposits. The Aquitanian deposits of Aquitaine contain the earliest European *Phacoides* (*Linga*) [included in *Phacoides* (*Here*) by Americans], which also occurs in the Anguilla formation. In America this group is well developed in the middle Eocene (Claiborne group), probably indicating its origin in American waters. Both *Metis* and *Phacoides* (*Linga*) belong to the group of genera now living in West Indian and west African waters, but not in the European seas.

The Anguilla fauna bears no resemblance to the Aquitanian fauna of the Piedmont basin.[12] It is more similar to the fauna of the Schio beds of the Venetian basin described by Oppenheim,[13] probably because the Schio beds include some coralliferous limestones.

So far as the mollusks are concerned, the correlation of the deposits of supposed Aquitanian age in the West Indies and Central America with the Aquitanian of Europe rests on their stratigraphic position rather than on any actual similarity.

The Aquitanian fauna of Europe abruptly entered the enlarged Tertiary basins and is totally different from the Oligocene faunas.[14] The work of Cossmann and Peyrot shows that more than 20 genera of pelecypods appear for the first time in the Aquitanian. Nine of these genera occur also in American Tertiary deposits. The following list shows their earliest appearance in the American Tertiary:

Aquitanian genera.	Earliest appearance in American Tertiary.
Ervilia	Thomonde and Baitoa formations, Chipola marl (Burdigalian).
Metis (= Capsa)	Anguilla formation (Aquitanian).
Psammobia (Gobræus) [= P. (Psammocola)]	Wilcox group (Lower Eocene).
Petricola (Rupellaria)	Gurabo formation (Helvetian). Yorktown formation (Pontian).
Tivela	Cercado formation (Burdigalian).

[11] C. W. Cooke: Tertiary mollusks from the Leeward Islands and Cuba. Carnegie Inst. Washington Pub. 291, 1919, pp. 105-152, 16 pls.

[12] The mollusks of these deposits are listed by F. Sacco: Les étages et les faunes du bassin tertiaire du Piémont. Soc. géol. France Bull., 4th ser., vol. 5, 1905, pp. 893-916, pls. 30-31 (maps). See page 900.

[13] P. Oppenheim: Ueber die Ueberkippung von S. Orso, das Tertiär des Tretto und Fauna wie Stellung der Schioschichten. Deutsch. geol. Gesell. Zeitschr., vol. 55, 1903, pp. 98-235, pls. 8-10.

[14] G. F. Dollfus: Essai sur l'étage Aquitanien. Service géol. France Bull., vol. 19, no. 124, 1909, 116 pp., 6 pls.

Cardium (Cardium)	Claiborne group (Middle Eocene).
Cardium (Cerastoderma)	Claiborne group (Middle Eocene).
Rochefortia	Duplin formation (Pontian).
Phacoides (Linga) [= P. (Here) in part]	Claiborne group (Middle Eocene).

The West Indian and Central American deposits that probably are Aquitanian in age have heretofore been referred to the Upper Oligocene. The difference between the faunas of probable Aquitanian age in the West Indies and Central America and of the Oligocene of the same region is not so striking as the difference between the European faunas of the same age. If the American deposits are of the same age as the Aquitanian, there is no reason for continuing to call them Upper Oligocene.

Burdigalian.—Deposits in the West Indies and Mexico that seem to be of Burdigalian age contain the earliest large Miocene faunas comparable in size to those of the Aquitanian basin. Two groups of faunas, for convenience called Upper and Lower Burdigalian, are recognized.

The so-called Lower Burdigalian includes the Baitoa formation of the Dominican Republic and the Thomonde formation of the Republic of Haiti. The known Baitoa fauna is small, consisting of 60 species, of which a preliminary list has been published.[15] The Thomonde formation has recently yielded more than 350 mollusks. A preliminary list of these fossils has recently been published.[16] It is the largest entirely undescribed Miocene fauna from the West Indies. The Baitoa and Thomonde formations, which are of approximately the same age, are the equivalent of the Chipola marl of Florida, but their fauna has a more tropical aspect. Their relation to the Miocene faunas of Aquitaine is not very clear. They are more similar to the Aquitanian and Burdigalian than to the Helvetian and Tortonian. In America the last *Alveinus* appears in the Baitoa and Thomonde formations, in the Chipola marl, and in the later deposits near Santa Rosa, Mexico. The last European *Alveinus* (*A. girondica* (Benoist), called *Lutetia* by Cossmann and Peyrot),[17] occurs in the Aquitaine basin, but is recorded from deposits of Aquitanian, Burdigalian, Helvetian, and Tortonian age. *Ervilia* is a conspicuous genus in the Baitoa, Thomonde, and Chipola faunas, where it first appears in American deposits. In Aquitaine, however, the earliest species comes from the Aquitanian stage.

[15] W. P. Woodring and W. C. Mansfield: A geological reconnaissance of the Dominican Republic. Dominican Rep. Geol. Survey Mem., vol. 1, 1921, pp. 113-114.

[16] W. P. Woodring and W. C. Mansfield: Geology of the Republic of Haiti. Republic Haiti Geol. Survey, 1924, pp. 179-190, 194-197.

[17] See G. D. Harris: The genera Lutetia and Alveinus. Paleontographica Americana, vol. 1, no. 2, 1920, 12 pp., pl. 17, 8 text figs.

The Cercado formation of the Dominican Republic and the deposits near Santa Rosa, Isthmus of Tehuantepec, Mexico, are called Upper Burdigalian. The Cercado formation carries about 500 mollusks, many of which have been described by Maury.[18] Preliminary lists of undescribed additional species collected by the U. S. Geological Survey expedition have been published.[19] Böse[20] described a few species from the beds near Santa Rosa. Mr. Wade, of the Transcontinental Petroleum Company, recently obtained a collection of about 300 species of mollusks from these beds. These mollusks are being described by Mr. Collins, of Johns Hopkins University.

The relations of these faunas to the Burdigalian fauna of Aquitaine are not very striking. The Cercado formation contains an undescribed species of the curious Indo-Pacific genus *Julia*. *Julia floridana* Dall, from the Chipola marl of Florida (Burdigalian), and a new species from the Bowden formation of Jamaica (Helvetian) are the only other American species. The only other fossil species are *J. girondica* (Benoist), from the Aquitanian of Aquitaine; *J. dourillei* Cossmann and Peyrot, from the Helvetian (?) of Aquitaine; and *J. lecointreæ* Dollfus and Dautzenberg, from the Helvetian of Touraine. In Aquitaine the earliest *Myrtæa* first appears in the Burdigalian, but in America there are Eocene and Oligocene species. The earliest American *Tivela* comes from the Cercado formation, but in Europe the genus first appears in the Aquitanian. The Burdigalian of Aquitaine carries the earliest *Macoma*, but in America the earliest species comes from the Tampa formation of Florida (Aquitanian). The Santa Rosa fauna is less tropical than the Cercado fauna. It contains *Alveinus*, like the earlier Baitoa and Thomonde faunas. The Santa Rosa beds have furnished the only American *Spirulirostra*, recently described by Berry.[21] The type species of this genus comes from the Helvetian of the Piedmont basin. Other species have been described from the Oligocene of Galicia and the Miocene of northern Germany and Australia. The Santa Rosa fauna contains the exotic genus *Euthria*, which is common in the Miocene and Pliocene deposits of the Mediterranean region and is now living in the Mediterra-

[18] C. J. Maury: Santo Domingo type sections and fossils. Bull. Am. Paleontology, vol. 5, 1917, pp. 165-459, pls. 27-68, 1 text fig. The Cercado mollusks are those described from Bluff 2 and Bluff 3, Rio Mao; Zone G, Rio Gurabo; Zones H and I, Rio Cana.

[19] W. P. Woodring and W. C. Mansfield: A geological reconnaissance of the Dominican Republic. Dominican Rep. Geol. Survey Mem., vol. 1, 1921, pp. 116-130.

[20] E. Böse: Sobre algunas faunas terciarias de México. Inst. geol. México Bol. 22, 1906, pp. 18, 23-27.

[21] E. W. Berry: An American Spirulirostra. Am. Jour. Sci., 5th ser., vol. 3, 1922, pp. 327-334, 5 text figs.

nean Sea. Some of the Santa Rosa genera indicate that the fauna is of Helvetian age rather than Burdigalian.

Although many genera that occur in the deposits of probable Burdigalian age in the West Indies and Mexico are recorded in the Burdigalian deposits of Aquitaine, the development of the faunas in the two regions is essentially provincial. The correlation of the American deposits with the European rests chiefly on their stratigraphic position.

Helvetian.—Widely distributed deposits in the West Indies and Central America carry a large fauna remarkably similar to the Helvetian of the Mediterranean region. The Gurabo formation of the Dominican Republic has about 400 mollusks, many of which have been described by Maury.[22] Preliminary lists of additional species have been published in the report on the geology of the Dominican Republic.[23] The Bowden formation of Jamaica has a fauna of fully 600 species. Guppy,[24] Guppy and Dall,[25] Dall,[26] and Pilsbry[27] have described some of these mollusks. I am now completing a revision of a monograph of the Bowden fauna.

[22] C. J. Maury: Santo Domingo type sections and fossils. Bull. Am. Paleontology, vol. 5, 1917, pp. 165-459, pls. 27-68, 1 text fig. The Gurabo mollusks are those described from Bluff 1, Rio Mao; Zones A-F, Rio Gurabo; *Arca patricia* beds, Rio Cana.

Virtually all the mollusks described by Sowerby and Guppy are from the Gurabo formation. G. B. Sowerby: Descriptions of new species of fossil shells found by J. S. Heniker [*sic*], Esq. Geol. Soc. London Quart. Jour., vol. 6, 1849, pp. 44-53, 2 pls. R. J. L. Guppy: On the Miocene fossils of Haiti. Geol. Soc. London Quart. Jour., vol. 32, 1876, pp. 516-532, 2 pls.

Gabb described many unfigured Miocene species from the Dominican Republic, but as his collection was obtained from almost all the Miocene beds of the country, it has no stratigraphic value. W. M. Gabb: On the topography and geology of Santo Domingo. Am. Philos. Soc. Trans., new series, vol. 15, 1873, pp. 49-260, 2 maps. Pilsbry has recently published a fully illustrated revision of the Gabb collection. H. A. Pilsbry: Revision of W. M. Gabb's Tertiary Mollusca of Santo Domingo. Acad. Nat. Sci. Philadelphia Proc., vol. 73, 1922, pp. 305-435, pls. 16-47, 48 text figs.

[23] W. P. Woodring and W. C. Mansfield: A geological reconnaissance of the Dominican Republic. Dominican Rep. Geol. Survey Mem., vol. 1, 1921, pp. 137-151.

[24] R. J. L. Guppy: On the Tertiary Mollusca of Jamaica. Geol. Soc. London Quart. Jour., vol. 22, 1866, pp. 281-295, pls. 16-18. On the relations of the Tertiary formations of the West Indies: Geol. Soc. London Quart. Jour., vol. 22, 1866, pp. 570-590, pl. 26. Notes on West Indian geology, with remarks on the existence of an Atlantis in the early Tertiary period, and descriptions of some new fossils from the Caribbean region: Geol. Mag., Dec. 1, vol. 4, 1867, pp. 49-501, 6 text figs. On some new Tertiary fossils from Jamaica: Sci. Assoc. Trinidad Proc., vol. 2, no. 2, 1873, pp. 72-88, pls. 1-2. On the West Indian Tertiary fossils: Geol. Mag., Dec. 2, vol. 1, 1874, pp. 404-411, 433-446, pls. 16-18. Supplement to the paper on West Indian Tertiary fossils: Geol. Mag., Dec. 2, vol. 2, 1875, pp. 41-42. On the Recent and Tertiary species of Leda and Nucula found in the West Indies, with notices of West Indian shells: Sci. Assoc. Trinidad Proc., pt. 12 [vol. 2], 1882, pp. 168-180, pl. 7.

[25] R. J. L. Guppy and W. H. Dall: Descriptions of Tertiary fossils from the Antillean region. U. S. Nat. Mus. Proc., vol. 19, 1896, pp. 303-331, pls. 27-30.

[26] W. H. Dall: Contributions to the Tertiary fauna of Florida. Wagner Free Inst. Sci. Philadelphia Trans., vol. 3, 1890-1903, 6 pts. Many pelecypods from the Bowden formation are described in parts 4-6.

[27] H. A. Pilsbry: Scaphopoda of the Jamaican Oligocene and Costa Rican Pliocene. Acad. Nat. Sci. Philadelphia Proc., vol. 63, 1911, pp. 165-169, 5 text figs.

Mollusks from the Gatun formation of the Canal Zone have been described by Dall,[28] Toula,[29] Brown and Pilsbry,[30] and Cossmann.[31] Very large collections in the United States National Museum have never been examined. Olsson[32] has recently described more than 300 species from the Gatun formation of Costa Rica. In the same report he also describes some species from the Canal Zone that have not been discovered in Costa Rica. The total described fauna of the Gatun formation in Panama and Costa Rica consists of about 400 species. According to Olsson,[33] the deposits in Costa Rica include higher beds than those in the Canal Zone, and some of them may be Upper Miocene. Many collections in the United States National Museum from Costa Rica have not been examined.

The resemblance of these West Indian and Central American Middle Miocene faunas to the Helvetian of the Piedmont basin is very striking. Perhaps this resemblance would lose some of its force if comparable Aquitanian and Burdigalian faunas were known from the Mediterranean region. The resemblance is particularly close in some families; for example, the Ledidæ, Malletiidæ, Arcidæ, Lucinidæ, Ranellidæ, Septidæ (= Tritonidæ), Olividæ, Mitridæ, Marginellidæ, Columbellidæ, Cassidæ, Terebridæ, and Conidæ. *Leda* (*Lembulus*), two groups of *Yoldia*, and *Neilo* are the only groups of Ledidæ, Malletidæ, and Arcidæ in the Piedmont Helvetian deposits that are not also known in the West Indian Helvetian beds. The Bowden formation contains all of the seven groups of Arca recorded by Sacco in the Helvetian of the Piedmont basin. Of the 12 groups of Lucinidæ in the Italian Helvetian, only two—*Lucina* (*Lorpinus*) and *Loripes*—do not occur in the Bowden formation. The following is a list of common Helvetian genera in both regions that are not now living in the Mediterranean Sea:

Leda (Jupiteria)	Oliva
Tindaria	Olivella
Isognomon (usually called Perna or Pedalion)	Ancillaria
	Latirus

[28] W. H. Dall: Contributions to the Tertiary fauna of Florida. Wagner Free Inst. Sci. Philadelphia Trans., vol. 3 (6 pts.), 1890-1903. Some pelecypods from the Gatun formation are described in parts 4-6.

[29] F. Toula: Ein jungtertiäre Fauna von Gatun am Panama-Kanal. K.-k. geol. Reichsanstalt Jahrb., vol. 58, 1909, pp. 173-670, pls. 25-28, 15 text figs.; idem, vol. 61, 1911, pp. 487-530, pls. 30, 31.

[30] A. P. Brown and H. A. Pilsbry: Fauna of the Gatun formation, Isthmus of Panama. Acad. Nat. Sci. Philadelphia Proc., vol. 63, 1911, pp. 336-373, pls. 22-29, 3 text figs.; idem, vol. 64, 1913, pp. 500-519, pls. 22-26, 5 text figs.

[31] M. Cossmann: Étude comparative de fossiles miocéniques recueillis à la Martinique et à l'Isthme de Panama. Jour. Conchyl., vol. 61, 1913, pp. 1-64, pls. 1-5.

[32] A. A. Olsson: The Miocene of northern Costa Rica. Bull. Am. Paleontology, vol. 9, 1922, pp. 179-460, pls. 4-35.

[33] Idem, p. 20.

Plicatula
Phacoides (Cardiolucina) [included in P. (Cavilucina) by Americans]
Phacoides (Linga) [included in P. (Here) by Americans]
Codakia (Codakia)
Phacoides (Pleurolucina) [called P. (Here) by Sacco]
Metis (called Capsa by most Europeans)
Murex (Pteronotus)
Melongena
Distorsio (called Persona by most Europeans)
Bursa (called Apollon by most Europeans)
Phos
Lyria
Cassis
Sconsia
Morum (Oniscidia)
Malea
Ficus (called Ficula or Pyrula by most Europeans)
Strombus
Terebra (Fusoterebra)
Conus (several groups)
Erato
Cancellaria (Trigonostoma)
Cancellaria (Aphera)
Rissoina (Rissolina)
Rissoina (Zebinella)
Rissoina (Zebina)
Acteocina

The following additional non-Mediterranean genera recorded by Sacco from the Tortonian, but not from the Helvetian, probably occur in Helvetian deposits of other parts of the Mediterranean region. All these genera are common West Indian Miocene fossils:

Crassatellites (called Crassatella by most Europeans)
Protocardia (Nemocardium)
Xancus (called Turbinella by most Europeans)
Amalthea
Cheilea (called Mitrularia by most Europeans)

Barbatia (*Obliquarca*) and *Myrtæa* (*Myrteopsis*) are two extinct groups that occur in the Helvetian deposits of Italy and the West Indies. The Columbellid genus described by Sacco[34] as *Thiarinella* seems to be the extinct genus *Metulella,* one of the most characteristic West Indian Helvetian genera.

Cardiums of the subgenus *Cardium* occur in the Helvetian deposits of both regions, but are no longer living in the West Indies. Olsson[35] has recently described a *Halia* from the Gatun formation of Costa Rica. This genus occurs in the Helvetian deposits of Italy and is now living only on the west African coast and northward to Spain.

The similarity to the Helvetian fauna of Aquitaine is not so striking. *Noetia* is one of the exotic genera in the Tertiary deposits of Aquitaine, where it is represented by *Noetia okeni* (Mayer)[36] [called *Arca* (*Ana-*

[34] F. Sacco: I molluschi dei terreni terziarii del Piemónte e della Liguria, pt. 6, 1890, p. 56, pl. 2, fig. 74.
[35] A. A. Olsson: Bull. Am. Paleontology, vol. 9, 1922, pp. 251-252, pl. 7, fig. 7.
[36] P. G. Sheldon: Atlantic slope Arcas. Paleontographica Americana, vol. 1, no. 1, 1916, p. 69.

dara) by Cossmann and Peyrot]. This species is confined to the Aquitanian and Burdigalian of Aquitaine, but also occurs in the Helvetian of Touraine [called *Arca* (*Anadara*) by Dollfus and Dautzenberg]. It is the only known European species of the genus. In the American Tertiary the earliest species is in the Gatun formation (Helvetian).

Other less spectacular genera now living in both the Mediterranean Sea and the West Indies are represented in the Helvetian deposits of both regions.

Despite the resemblance shown by many genera, the West Indian Helvetian faunas are clearly West Indian and the Mediterranean Helvetian faunas have an unmistakable European aspect. The following is a list of common West Indian Helvetian genera unknown in the European deposits:

Yoldia (Orthoyoldia)
Cunearca
Placunanomia
Mytilopsis
Verticordia (Trigonulina)
Venericardia (Pleuromeris)
Echinochama
Lucina (Lucina)
Phacoides (Callucina)
Phacoides (Parvilucina)
Phacoides (Bellucina)
Phacoides (Parvilucina)
Cardium (Trigoniocardia)
Clementia
Cyclinella
Chione
Tellina (Scissula)
Macoma (Cymatoica)
Corbula (Bothrocorbula)
Cancellaria (Cancellaria)
Solenosteira
Metula
Strombina
Crepitacella
Gaza (Callogaza)

A large number of typical European genera that are common fossils in the Mediterranean Helvetian deposits have never been discovered in American Tertiary deposits. These genera are particularly abundant in the families Cardiidæ, Veneridæ, Tellinidæ, Rissoidæ, and Trochidæ.

Tortonian.—The Cerros de Sal formation of the Dominican Republic is the only West Indian formation of supposed Tortonian age having a relatively large molluscan fauna. A preliminary list of 75 species has been published.[37] It is an almost pure West Indian fauna, with the exception of the two Pacific genera, *Strombina* and *Solenosteira.*

The Cerros de Sal fauna affords no adequate basis of comparison with the Tortonian fauna of the Piedmont basin. This European Tortonian fauna resembles the preceding Helvetian fauna in many features, and therefore is like the West Indian Helvetian faunas; but the similarity between the Mediterranean and West Indian faunas reaches its climax

[37] W. P. Woodring and W. C. Mansfield: A geological reconnaissance of the Dominican Republic. Dominican Rep. Geol. Survey Mem., vol. 1, 1921, pp. 163-164.

in the Helvetian and thereafter declines, except for a slight increase in the Astian, as is graphically shown in figure 4. In this graph, as in figure 3, the Tortonian fauna of Aquitaine fails to agree with the other faunas.

PLIOCENE

The Pliocene faunas from the West Indies and Central America are very meager. Gabb[38] described a so-called Pliocene fauna from Port

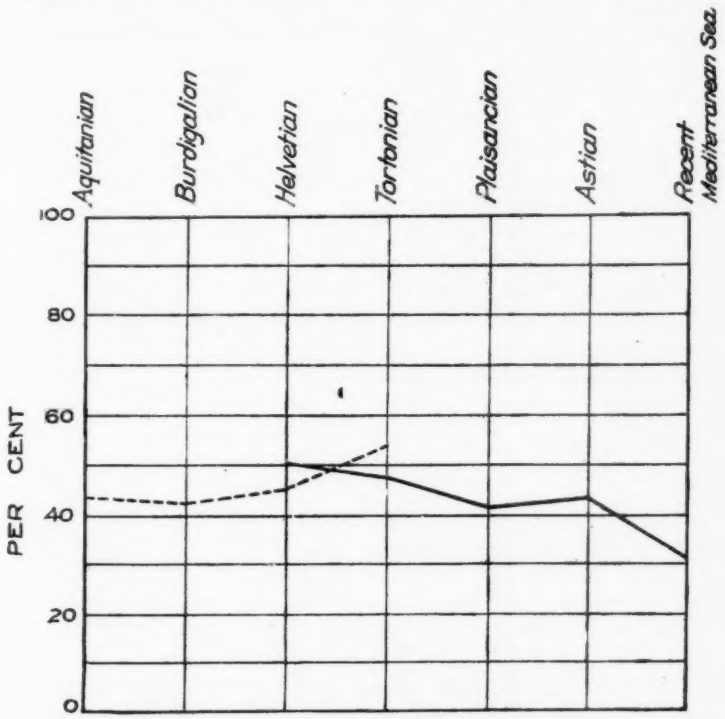

FIGURE 4.—*Graph showing Percentage of West Indian Miocene Genera in Miocene and Pliocene Faunas of Piedmont and Aquitaine Basins*

Solid line represents Piedmont basin; broken line represents Aquitaine basin.

Limon, Costa Rica. It has been known for some time that this is a mixed fauna, as deposits of both Miocene and Pliocene age crop out at Port

[38] W. M. Gabb: Descriptions of new species of fossils from the Pliocene clay beds between Limon and Moen, Costa Rica, together with notes on previously known species from there and elsewhere in the Caribbean area. Acad. Nat. Sci. Philadelphia Jour., series 2, vol. 8, 1881, pp. 349-380, pls. 45-47.

Limon.[39] Olsson[40] has recently described these deposits of Miocene and Pliocene age. The Toro limestone of the Panama Canal Zone may be Pliocene, but its fauna is negligible. Deposits of Pliocene age in the Republic of Haiti have recently been described, but their known molluscan fauna consists of only 17 species. It is a pure West Indian fauna.

If a large Pliocene fauna were discovered in the West Indies, it probably would contain a small percentage of exotic and extinct genera. The Pliocene Caloosahatchee formation of Florida carries a large subtropical fauna, including the Pacific genus *Solenosteira* and the extinct genera *Corbula* (*Bothrocorbula*) and *Perplicaria*.

There are no Pliocene faunas in the West Indies and Central America comparable to the Pliocene faunas of the Piedmont basin. The resemblance of the Italian Helvetian and Tortonian faunas to the Helvetian faunas of the West Indies and Central America continues as a prominent but diminished feature of the Plaisancian and Astian faunas (see figure 4). This resemblance continues even in the early Quaternary Sicilian stage. Some of the living West Indian species are known by names given by Seguenza to fossils from Sicily. Refined work is gradually eliminating these names from the living West Indian fauna, but the confusion of fossil and living species in the two regions gives an indication of the similarity of some elements of the faunas.

[39] T. W. Vaughan: U. S. Nat. Mus. Bull. 103, 1919, p. 221.
[40] A. A. Olsson: Bull. Am. Paleontology, vol. 9, 1922, pp. 183-184.

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